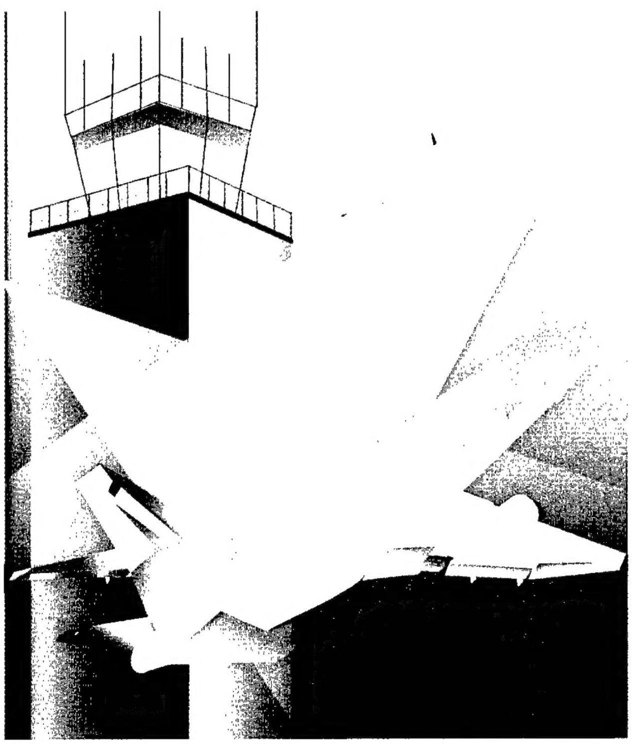
Collision With Trees on Final Approach
Federal Express Flight 1478
Boeing 727-232, N497FE
Tallahassee, Florida
July 26, 2002



Aircraft Accident Report

NTSB/AAR-04/02

PB2004-910402
Notation 7501B

National
Transportation
Safety Board
Washington, D.C.

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Adopted June 8, 2004

National Transportation Safety Board
490 L'Enfant Plaza, S.W.
Washington, D.C. 20594

National Transportation Safety Board. 2004. ***Collision With Trees on Final Approach, Federal Express Flight 1478, Boeing 727-232, N497FE, Tallahassee, Florida, July 26, 2002.*** **Aircraft Accident Report NTSB/AAR-04/02. Washington, DC.**

Abstract: This report explains the accident involving Federal Express flight 1478, a Boeing 727-232F, N497FE, which struck trees on short final approach and crashed short of runway 9 at the Tallahassee Regional Airport, Tallahassee, Florida. Safety issues in this report focus on flight crew performance, flight crew decision-making, pilot fatigue, and Federal Aviation Administration (FAA) certification of pilots with color vision deficiencies. Safety recommendations concerning these issues are addressed to the FAA.

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Contents

Abbreviations

AC	advisory circular
AD	airworthiness directive
agl	above ground level
AIM	Aeronautical Information Manual
ALAR	approach and landing accident reduction
ARFF	aircraft rescue and firefighting
ARTCC	air route traffic control center
ASOS	automated surface observation system
ATC	air traffic control
ATCT	air traffic control tower
ATP	airline transport pilot
bpm	breaths per minute
BUF	Buffalo Niagara International Airport
CFIT	controlled flight into terrain
CFM	company flight manual
CFR	*Code of Federal Regulations*
CRM	crew resource management
CTAF	common traffic advisory frequency
CVR	cockpit voice recorder
DOT	Department of Transportation
EGPWS	enhanced ground position warning system
EPR	engine pressure ratio
FAA	Federal Aviation Administration
FALANT	Farnsworth Lantern
FDR	flight data recorder

FL	flight level
FOM	flight operations manual
FOTM	flight operations training manual
fpm	feet per minute
GAME	Guide for Aviation Medical Examiners
GFK	Grand Forks International Airport
GPWS	ground proximity warning system
Hg	mercury
IFR	instrument flight rules
ILS	instrument landing system
IOE	initial operating experience
MEM	Memphis International Airport
msl	mean sea level
NASA	National Aeronautics and Space Administration
NATCA	National Air Traffic Controllers Association
nm	nautical mile
NPRM	notice of proposed rulemaking
NWS	National Weather Service
PAPI	precision approach path indicator
PIP	pseudoisochromatic plate
pph	pounds per hour
S/N	serial number
SHV	Shreveport Regional Airport
SODA	Statement of Demonstrated Ability
TCAS	traffic collision avoidance system
TLH	Tallahassee Regional Airport
TRACON	terminal radar approach control
USAFSAM	U.S. Air Force School of Aerospace Medicine
VASI	visual approach slope indicator

VOR	Very High Frequency Omnidirectional Radio Range
VSI	vertical speed indicators
YOW	Ottawa MacDonald Cartier International Airport
YWG	Winnepeg International Airport

Executive Summary

On July 26, 2002, about 0537 eastern daylight time, Federal Express flight 1478, a Boeing 727-232F, N497FE, struck trees on short final approach and crashed short of runway 9 at the Tallahassee Regional Airport (TLH), Tallahassee, Florida. The flight was operating under the provisions of 14 *Code of Federal Regulations* Part 121 as a scheduled cargo flight from Memphis International Airport, in Memphis, Tennessee, to TLH. The captain, first officer, and flight engineer were seriously injured, and the airplane was destroyed by impact and resulting fire. Night visual meteorological conditions prevailed for the flight, which operated on an instrument flight rules flight plan.

The National Transportation Safety Board determines that the probable cause of the accident was the captain's and first officer's failure to establish and maintain a proper glidepath during the night visual approach to landing. Contributing to the accident was a combination of the captain's and first officer's fatigue, the captain's and first officer's failure to adhere to company flight procedures, the captain's and flight engineer's failure to monitor the approach, and the first officer's color vision deficiency.

The safety issues in this report focus on flight crew performance, flight crew decision-making, pilot fatigue, and Federal Aviation Administration (FAA) certification of pilots with color vision deficiencies. Safety recommendations concerning these issues are addressed to the FAA.

1. Factual Information

1.1 History of Flight

On July 26, 2002, about 0537 eastern daylight time,[1] Federal Express (FedEx) flight 1478, a Boeing 727-232F (727), N497FE, struck trees on short final approach and crashed short of runway 9 at the Tallahassee Regional Airport (TLH), Tallahassee, Florida. The flight was operating under the provisions of 14 *Code of Federal Regulations* (CFR) Part 121 as a scheduled cargo flight from Memphis International Airport (MEM), in Memphis, Tennessee, to TLH. The captain, first officer, and flight engineer were seriously injured, and the airplane was destroyed by impact and resulting fire. Night visual meteorological conditions prevailed for the flight, which operated on an instrument flight rules (IFR) flight plan.

The accident flight crew reported for the accident flight in MEM at least 1 hour before the flight's scheduled departure time of 0412,[2] as required by FedEx. The airplane's departure from MEM was delayed slightly because of an adjustment to a cargo pallet; the airplane was pushed back about 0424. According to postaccident pilot interviews, cockpit voice recorder (CVR)[3] and flight data recorder (FDR) evidence, and air traffic control (ATC) records, the climb and cruise phases of the flight were routine and uneventful. The first officer was the flying pilot, while the captain performed the non-flying pilot duties for the accident flight.

According to the CVR transcript, about 0511, the flight engineer received the TLH weather information from the Gainesville Flight Service Station, which indicated: scattered clouds at 100 feet, 18,000 feet, and 25,000 feet; wind from 120° at 5 knots; visibility 9 statute miles; temperature and dew point 22° C (Celsius); and altimeter setting 30.10 inches of mercury (Hg). The flight engineer related this information to the captain and first officer and asked which runway they would use at TLH. About 0512:41, the captain stated that they would land on runway 27 at TLH.

The CVR indicated that about 0513:13, a controller at Atlanta Air Route Traffic Control Center (ARTCC) cleared the pilots of flight 1478 to descend to and maintain flight level (FL) 240[4] at their discretion. The captain acknowledged the clearance. The flight engineer subsequently contacted FedEx ramp personnel at TLH and advised them that flight 1478 was 25 to 30 minutes from TLH, "lookin' for a parkin' spot and the

[1] Unless otherwise indicated, all times are eastern daylight time, based on a 24-hour clock.

[2] The flight's scheduled departure time was 0312 in MEM local time (MEM is located in the central daylight time zone).

[3] The CVR recorded the last 32 minutes and 12 seconds of cockpit communications before the accident. See appendix B for a complete transcript of the CVR.

[4] Flight level (FL) 240 is an altitude of 24,000 feet mean sea level (msl), based on an altimeter setting of 29.92 inches Hg.

power." TLH ramp personnel advised them to use gate number 2 and to park facing south. The flight engineer then briefed the captain and first officer regarding parking at TLH and, in accordance with company procedures, advised them that FedEx considered TLH a moderate controlled flight into terrain (CFIT) risk.[5]

About 0515:32, Atlanta ARTCC instructed the pilots of flight 1478 to contact Jacksonville ARTCC and the captain acknowledged the instructions. At 0515:52.3, the CVR recorded the captain, stating, "Jacksonville center uh good morning, FedEx fourteen seventy eight, two nine oh, discretion to two four oh." The Jacksonville air traffic controller responded, "FedEx 1478, Jax center roger, descend at pilot's discretion maintain niner thousand, Tallahassee altimeter three zero one zero." The captain acknowledged the clearance then announced the target airspeeds[6] for the approach to the first officer.

About 0516:38, the captain questioned the flight engineer about the weather information, stating, "one thousand scattered, ten miles, uhh is zat what it said…there?" About 0516:43 (while the captain was finishing his statement), the first officer began the approach briefing for runway 27 at TLH, stating, in part, "we'll plan on a visual to runway 27…We'll back it up with this…ILS[[7]] runway 27 full procedure…272 is the final approach course inbound." The first officer stated that the minimum safe altitude was 3,300 feet mean sea level (msl) "all the way around…missed approach will be as published and we'll talk to 'em and see if we can get something better….runway's 8,000 [feet long], plan on rollin' out to the end…got a PAPI[[8]] on the left-hand side…pilot-controlled lighting,[[9]] so if you can…click it seven times I'd appreciate it." About 0518:30, the first officer stated, "all right, start on down," and the captain responded, "all right." The captain then radioed Jacksonville ARTCC, stating, "uh, Atlanta FedEx uh fourteen seventy eight, leaving two nine oh for uh, nine thousand."

According to the CVR transcript, about 0519:38, the first officer asked, "you wanna land on nine if we see it?" He added, "we got a PAPI on nine, too." The captain

[5] The Federal Aviation Administration (FAA) defines CFIT as "an event where a mechanically normal functioning airplane is inadvertently flown into the ground, water, or an obstacle" (see <http://www/faa.gov/avr/avs/cfit/volume1/titlepg.pdf>). FedEx's Flight Operations Manual (FOM) contains a similar definition. For additional information regarding FedEx's determination of CFIT risk, see section 1.17.1.1.

[6] The captain announced the target airspeeds as follows: "V_{ref} one thirty seven…uhhh bug at uh one forty seven…one fifty two, one sixty two, one ninety two, two oh two."

[7] ILS refers to the instrument landing system.

[8] The PAPI, or precision approach path indicator, light system at TLH consists of four boxes of lights that provide a visual indication of an airplane's position on the glidepath for the associated runway. If an airplane is on glidepath, two boxes should display white lights and two boxes red lights. If an airplane is beneath the glidepath, more red lights are visible to the pilots; if an airplane is above the glidepath, more white lights are visible. For additional information regarding the TLH PAPI lighting system, see section 1.10.2.

[9] During hours that TLH air traffic control tower (ATCT) is closed, all runway, taxiway, and approach lighting systems on the airport are pilot-controlled and can be activated by a pilot keying the microphone with the radio tuned to the airport's common traffic advisory frequency (CTAF). Keying the airplane microphone activates the airport lighting as follows: three times (within 5 seconds) results in low intensity, five time results in medium intensity, and seven times results in high intensity.

responded, "yeah, maybe...be a longer taxi for us, but...way we're comin' in probly two seven be about as easy as any of 'em." The first officer said, "okay." The pilots initiated the in-range checklist about 0521:57 and completed it about 0522:20. During this time, the CVR recorded a sound similar to the microphone being keyed six times in about 1.3 seconds.

The CVR indicated that about 0522:46, Jacksonville ARTCC cleared the pilots of flight 1478 to descend and maintain 3,000 feet msl at their discretion. About 0523:33, the Jacksonville ARTCC controller instructed the pilots to contact him on another frequency. At 0523:49.2, the captain reported on the new frequency, stating, "and Atlanta FedEx fourteen seventy eight with you, one thirty five thirty two." The Jacksonville ARTCC controller asked if they had TLH weather, and the captain confirmed that they did. About 0524:03, the controller advised them to expect a visual approach into TLH and to report when they had the airport in sight.

According to the CVR, about 0524:23, the captain stated, "runway nine...PAPI on the left side...I don't know, you wanna try for nine?" The first officer responded, "we're pointed in the right direction, I don't know, like you said...kinda a long...taxiback." The captain said, "yeah, that'd be all right." The first officer further stated, "I always thought you were supposed to land with the prevailing wind...at an uncontrolled...," and the captain responded, "well, at 5 knots, it really...the only advantage you have, landing to the west you have the...glideslope...which you don't have to the east." The captain asked the first officer if he was familiar with TLH, and the first officer replied that he was not.

About 0527:47, the flight engineer advised TLH ground personnel that flight 1478 was 5 minutes out. The ramp agent indicated that ground power was available for the airplane and that he would arrange for transportation for them to the layover hotel.[10] Consistent with FedEx policy, the flight engineer then asked the captain and first officer if they wanted to perform the approach checklist. About 0528:26, the first officer asked, "we ever decide if we're goin' nine or two seven?" The captain responded, "yeah, we can do nine if you want to." About 0528:30, the first officer stated, "okay, runway nine, visual runway nine PAPI on the left side...approach check." The flight engineer asked, "briefing?," and the first officer responded, "complete for runway nine."

The pilots continued the approach checklist and completed it about 0528:57. About 0529:53, the captain asked the first officer if he wanted to tell the ARTCC controller that they had TLH in sight. The first officer responded, "yeah. I don't see the runway yet, but I got the beacon." About 0530, the captain told the ARTCC controller that they had the airport in sight. Jacksonville ARTCC then cleared the pilots of flight 1478 for the visual approach into TLH and asked if they were aware that runway 18/36 was

[10] The pilots were scheduled to remain in Tallahassee for about 17 hours that day then depart TLH for MEM about 2315.

closed.[11] The captain responded, "no sir, but...we're gonna use runway nine." Jacksonville ARTCC repeated the visual approach clearance, adding, "report your down time...change to advisory [frequency] approved."

About 0530:32, the CVR recorded sounds similar to a microphone being keyed five times within about 1.3 seconds. About 7 seconds later, the captain radioed "Tallahassee uh FedEx fourteen seventy eight uh extended uh left base leg for runway nine." The first officer indicated that he thought he saw the runway about 0530:56; he called for "flaps 2" about 0531:10 and "flaps 5" about 12 seconds later. About 0532:34, the first officer stated, "I hope I'm lookin' in the right spot here." The captain responded, "see that group of bright lights kinda to the south down there and you see the beacon in the middle of it?...right over there...you're kinda on about...ten mile left base or so." The first officer then indicated that he had been "looking at the wrong...flashin' light."[12] About 0533:05, the first officer repeated, "I was lookin' at the wrong light," and the captain responded, "yeah okay, yeah." The first officer added, "yeah, with the direction I took, we coulda used [runway] 27, eh?," and the captain responded, "yeah, it dudn't matter. Yeah, it's about...ten miles south of the VOR."[13]

About 0534:11, the captain stated, "I guess the lights came on, if not I'll click 'em again here...when we get a little closer." About 20 seconds later, the CVR recorded a sound similar to a microphone being keyed five times within about 1.5 seconds, and, at 0534:35, the captain said, "there we go." The first officer requested "flaps 15" about 0535:24. About 0535:31, the first officer stated, "gear down, before landing check;" about 2 seconds later, the CVR recorded a sound similar to the landing gear handle being operated followed by a sound similar to the nose gear door opening.

The CVR indicated that, about 0535:42, the captain advised TLH traffic that flight 1478 was turning onto final for runway 9. The flight engineer began the before landing checklist about 0535:54, stating, "landing gear," to which the captain responded, "down in three green." About 0535:59, the flight engineer stated, "autobrakes," and, about 0536:06, the captain responded, "not installed." About 0536:06, the first officer asked for "flaps 25," and the captain acknowledged the request. About 0536:08, the CVR recorded the flight engineer ask, "autospoilers?" and the captain's response of "not installed." About 0536:10, the flight engineer queried "flight and nav[igation] instruments?," and the captain responded, "cross-checked, no flags."

[11] The National Transportation Safety Board notes that the runway 18/36 closure information was published in the Airport Facility Directory, (on the Jeppesen-type salmon-colored page 10-10A for TLH [which listed local ATC, airport, and radar information]), and in the remarks section of the FedEx flight plan/release for flight 1478. In addition, Notice to Airmen 02-47 was issued on July 19, 2002, for the closure.

[12] A FedEx captain who regularly flies the MEM-to-TLH route told Safety Board investigators that a powerplant located a few miles north of TLH has a slow white strobe light that is frequently mistaken for the airport's rotating beacon. He stated that the powerplant light is in the line of sight for the airport for pilots arriving from the northwest and is often visible before the rotating beacon. He also stated that the green light of the TLH rotating beacon is "very hard to distinguish as green. It is very faint."

[13] VOR refers to the very high frequency omnidirectional radio range navigation aid.

About 0536:20, the first officer said, "sorry 'bout that…I was linin' up on that papermill or something." As the first officer started speaking, (at 0536:20.2), the CVR recorded the ground proximity warning system (GPWS) announce that the airplane passed through 1,000 feet above ground level (agl).[14] About 0536:23, the captain said, "that's all right, no problem."

About 0536:37, the airplane was slightly more than 2.5 nautical miles (nm) from the airport and was transitioning from an angled base-to-final leg to line up with the runway. The Safety Board's airplane performance study indicated that, about this time, the PAPI would have been displaying one white light and three red lights when viewed from the cockpit. About 0536:40, the PAPI display would have shown four red lights. (Figure 1 shows the airplane's descent profile in relation to the PAPI light indications, flap extension, the runway, and treetops. Figure 2 shows the same information with select CVR comments overlaid.) About this time, the power on the three engines increased from about 1.05 to 1.24 EPR (engine pressure ratio),[15] then, about 0536:41, the power to the engines decreased from 1.24 to 1.17 EPR. About 0536:43, as the airplane approached 500 feet, the captain asked the first officer if he wanted to go to flaps 30, and the first officer responded, "please." At 0536:47.8, the CVR recorded the GPWS announcement indicating that the airplane was passing through 500 feet agl. About 0536:49, the CVR recorded the captain stating, "stable." The Safety Board's airplane performance study indicated that, at this time, the airplane was 1.8 nm west of runway 9, descending through 500 feet agl at a vertical speed of 1,248 feet per minute (fpm),[16] with engine power settings of about 1.17 EPR and an airspeed of 152 knots.

[14] Evaluation of the accident airplane's GPWS indicated that the unit provided altitude advisories consistent with its design during the approach to TLH. Additionally, the investigation noted that the airplane's most rapid rate of descent during the later stages of the approach (more than 1,400 feet per minute [fpm] between 700 and 500 feet) did not meet the warning annunciation threshold for those altitudes; at those altitudes, the GPWS would have generated a "sink rate" warning at descent rates of 2,100 and 1,800 fpm, respectively.

[15] Engine pressure ratio (EPR) is a measurement of engine power output as a ratio of the total pressure of the gases in the exhaust pipe divided by the total pressure of the air entering the engine inlet.

[16] The Safety Board notes that the captain's and first officer's vertical speed indicators (VSIs) were not instantaneous and, therefore, may have displayed vertical speed information that lagged slightly behind the real-time vertical speed derived from the FDR data. According to the VSI manufacturer's simulation, the pilots' VSIs would have shown a rate of descent of at least 1,000 fpm when the airplane descended through 500 feet agl.

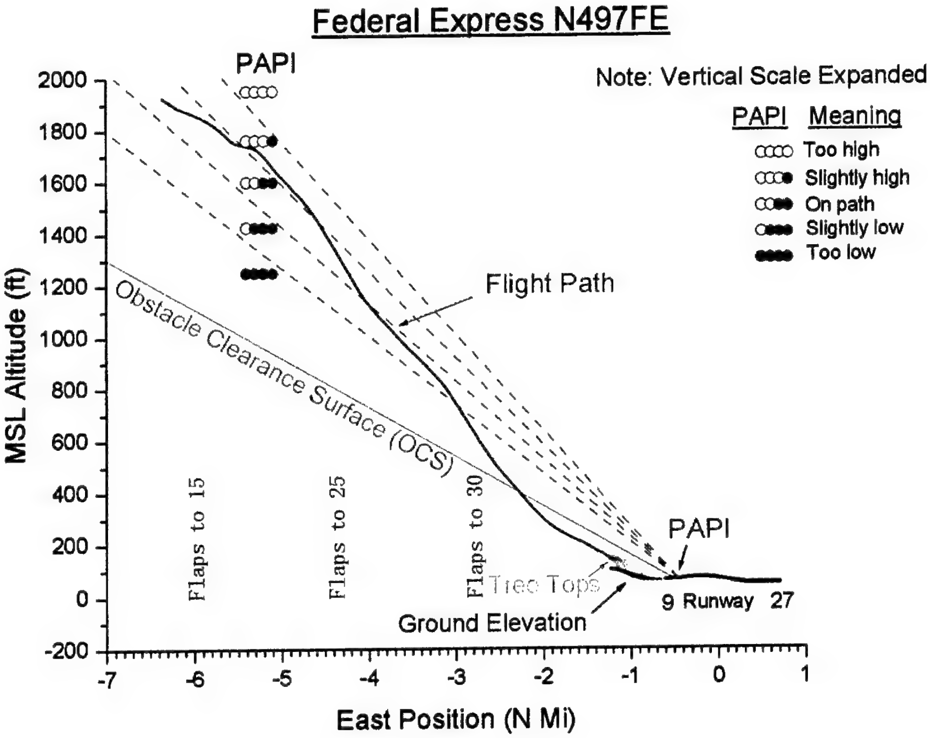

Figure 1. Descent profile of FedEx flight 1478.

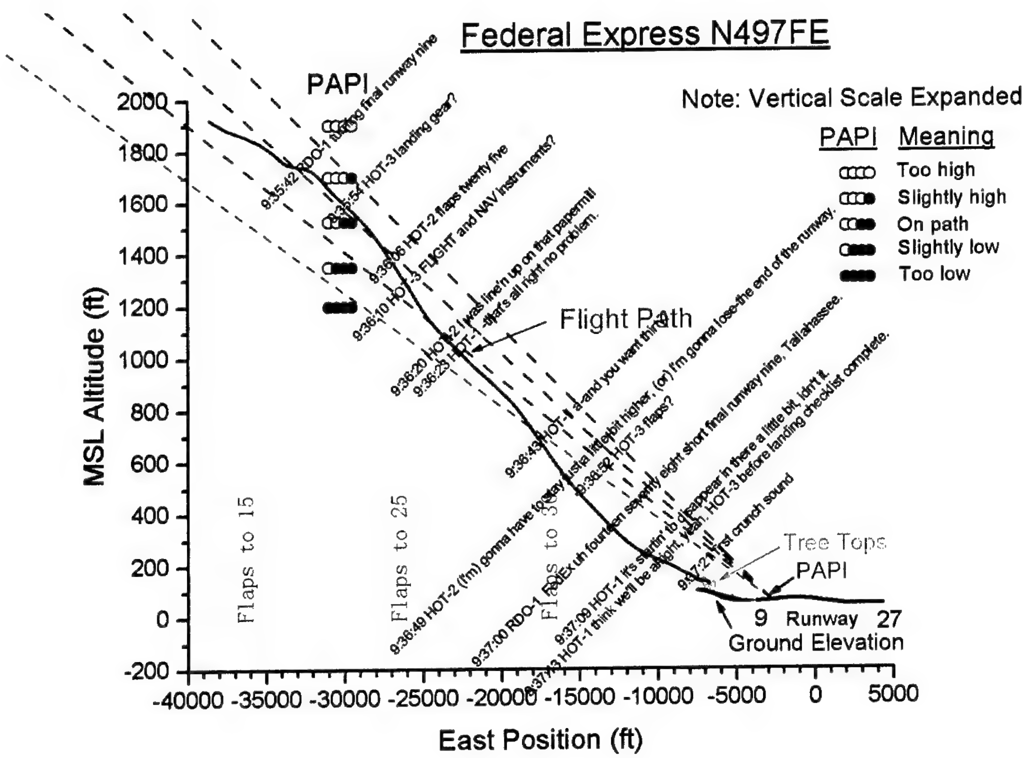

Figure 2. Descent profile of FedEx flight 1478, with select CVR comments overlaid.

Also about 0536:49, the CVR recorded the first officer stating, "[I'm] gonna have to stay just a little bit higher…I'm gonna lose the end of the runway." About 0536:51, the captain responded, "yeah…yeah, okay." About 0536:52, the flight engineer asked, "flaps?," and the captain responded, "thirty thirty green light." About 0536:56, the flight engineer asked, "landing clearance?," and the captain responded, "clear to land runway…nine."

About 0536:58, the FDR data indicated that the engine power began to increase from 1.17 EPR, reaching 1.20 EPR about 4 seconds later. At 0536:59.7, the captain advised TLH traffic that flight 1478 was on short final for runway 9. About 0537:09, the captain said, "it's startin' to disappear in there a little bit, [isn't] it? Think we'll be alright, yeah." The performance study indicated that, about this time, the airplane was 0.9 nm west of runway 9, descending through about 200 feet agl at a vertical speed of 528 fpm and an airspeed of 146 knots; the airplane performance study indicated that the PAPI indication observed from the cockpit would have been four red lights.

About 0537:13, the flight engineer announced that the before landing checklist was complete.[17] This announcement was the last flight crewmember statement recorded by the CVR. At 0537:14, the GPWS announced that the airplane passed 100 feet agl; FDR and airplane performance information indicated that, at this time, the airplane was 0.7 nm west of runway 9, descending at a vertical speed of 432 fpm and an airspeed of 144 knots and that the engine power had increased to about 1.34 EPR. At 0537:19.9, as the GPWS announced 50 feet agl, the engine power increased to about 1.46 EPR. At 0537:20.3, as the GPWS announced 40 feet agl, the No. 2 and No. 3 engine EPRs began to increase rapidly. At 0537:20.7, the CVR recorded the sound of a crunch, and, about 0537:21, the GPWS announced 30 feet agl. About 0537:22, the CVR recorded another crunch sound, and the No. 1 engine EPR began to increase rapidly. At 0537:22.6, the GPWS announced "bank angle, bank angle." The CVR transcript indicates that, about 0537:23, the sound of crunching began again and, about 0537:25, a loud squeal began; both sounds continued to the end of the recording at 0537:26.2. (Figure 3 shows the accident airplane's radar track into TLH overlaid on a map, with excerpted CVR comments.)

The airplane collided with trees in a right-wing-low, slightly nose-up attitude during the approach to runway 9 then impacted the ground, coming to rest on a heading of 260° degrees about 1,556 feet west-southwest of the runway. A postimpact fire ensued; however, the three flight crewmembers exited the airplane through the captain's side sliding cockpit window before the fire reached the cockpit. The accident occurred about 74 minutes before sunrise.

[17] Although the CVR did not record any discussion of the last four items on the 727 before landing checklist (fuel panel, hydraulic and brake system, antiskid, and landing lights), FedEx's 727 Company Flight Manual (CFM) indicates that those items are "to be completed silently."

During postaccident interviews,[18] all three crewmembers described a normal flight until the last seconds of the approach. The captain stated that the airplane was established on final as it descended through about 800 feet. He stated that during the approach, he observed "white pink, going to white red" on the PAPI and that, as the airplane descended, "we started picking up a few little wispy, I want to say clouds or mist, but it didn't obscure the airport." The captain stated that his last recollection was of a "white red" PAPI indication, then "we started feeling a little bumping, and the rest of it I don't recall." The captain stated that the last thing he remembered about the approach was that "everything visually looked normal, based on the runway and that's why I was somewhat shocked when I felt the thumping."

The first officer stated the following about the approach:

> Everything was running exactly the way it was supposed to run. When we got down closer to the field and we had slowed down and the field was in sight....and the wind was still prevailing down runway nine. And that's when I mentioned...should we go ahead and land on runway nine, since that's where the wind is. [The captain] said okay, that's fine. We were kinda lined up that direction anyway. And the speed was well within parameters...Got the nose pointed to the airport, started slowing down, started dirtying up...rolled out on the centerline on the PAPI...I remember specifically adding a touch of power because I recall rolling out on centerline but 2 knots slow and a hair under the bug...that's the last I can remember...I have no memory of the remainder of the flight.

[18] Safety Board investigators interviewed all three crewmembers as soon as possible after the accident. The flight engineer was interviewed in the hospital on July 27, 2002, the day after the accident. The captain was interviewed in the hospital on the next day, July 28. The first officer, whose injuries were more severe than the other crewmembers', was interviewed in his hometown of Brunswick, Maine, on August 31, 2002.

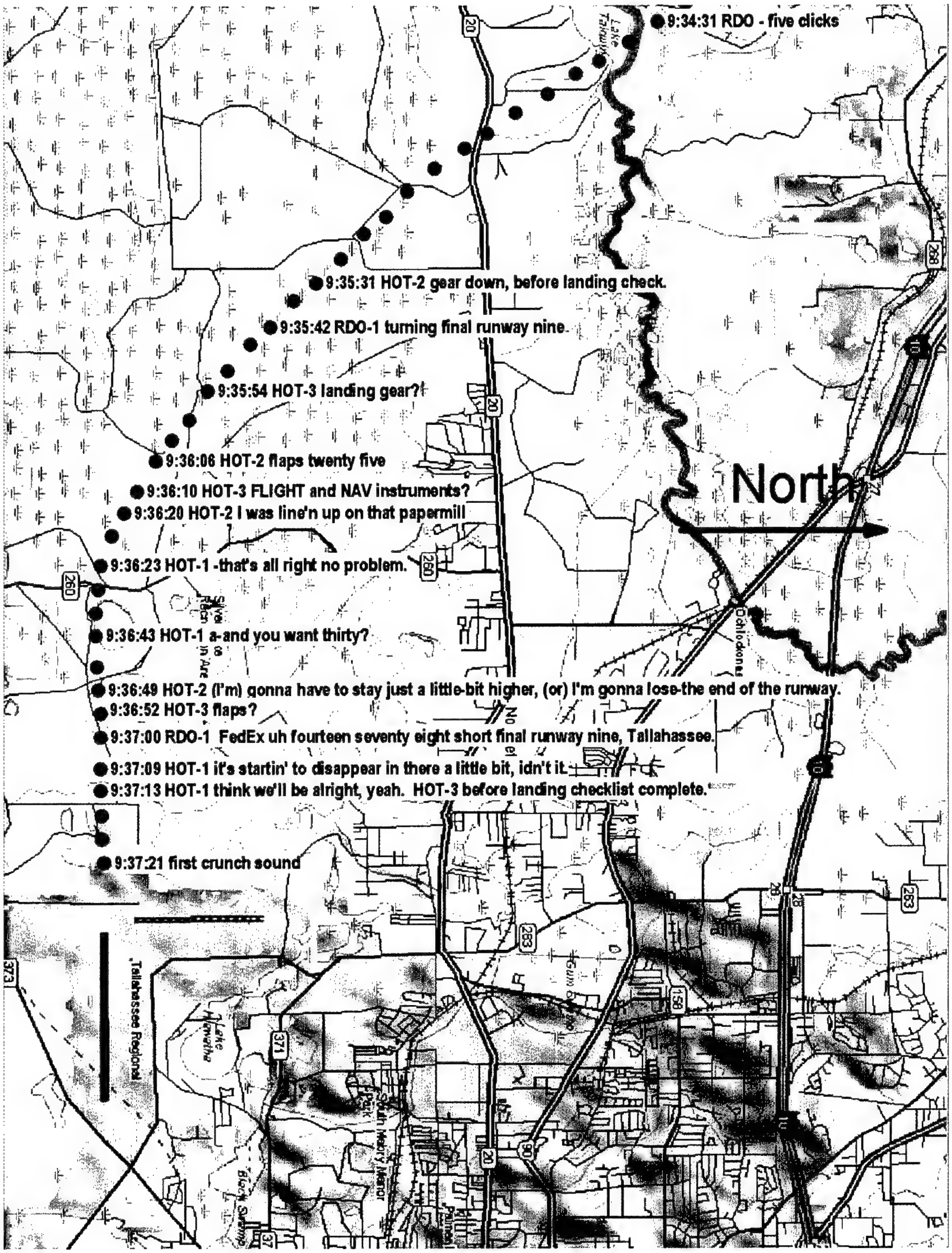

Figure 3. A map overlay of FedEx flight 1478's radar track into runway 9 at TLH, with excerpted CVR comments.

The first officer stated that when he first saw the PAPI lights, they indicated white next to red, showing that the airplane was on the glidepath. When investigators asked him to describe the PAPI system, the first officer described two white lights with two red lights next to each other. The first officer said that he would not have considered landing on runway 9 if it did not have the PAPI light guidance. He went on to state, "from the time I rolled out, I saw that I was on glideslope, added that power for the 2 knots, and it never changed. After that, since I have no memory of the remainder of the flight...I don't know where the rest of the flight went." When asked about power settings, the first officer told investigators that fuel flow for a normal visual approach would be 3,000 to 3,500 pounds per hour (pph) at 500 feet.[19]

The flight engineer told investigators that he first saw the airport about the same time the first officer remarked that he had the runway in sight, when the airplane was on a modified left base leg for runway 9. The flight engineer stated that, when he first saw the runway, he observed a white, a pink, and two red lights on the runway's four-light PAPI system. He further stated that, throughout the approach, he was scanning his instruments and looking outside for other air traffic and that, as they neared the runway, they could see the runway lights "plain as day, including the PAPI." He stated that the visibility was good during their approach and indicated that he did not observe any of the low, scattered clouds that were reported in the TLH weather observation.

According to the flight engineer, the pilots were not rushed during the approach to TLH. The flight engineer stated that, after they completed the before landing checklist, he turned to his instrument panel to scan the instruments.[20] He checked the fuel indicators, turned off the right air conditioning pack, and ensured that temperature, hydraulic, and electrical indications were good for landing. He stated that everything looked and felt normal until he started to feel like they were in turbulence. He said that when he felt the "turbulence" and looked out the front windshield, the airplane was in a slight right-wing-low attitude and he realized that they were going to hit something. None of the flight crewmembers indicated that they ever saw all red lights on the PAPI during the approach.

[19] According to the FedEx 727 CFM, fuel flows between 3,000 and 3,500 pph correspond to settings of 1.3 to 1.45 EPR. The accident airplane's FDR data showed that between 0536:20 and 0537:07, the engine power ranged from about 1.1 to about 1.25 EPR; the engine power did not exceed 1.3 EPR until about 10 seconds before impact.

[20] According to the FedEx 727 CFM, after the flight engineer completes the before landing checklist, he is to turn his seat "either full forward or first notch to the right of full forward" and be actively involved in the approach for the remainder of the flight. Postaccident fire damage precluded a determination of the flight engineer's seat position.

1.2 Injuries to Persons

Table 1. Injury chart.

Injuries	Flight Crew	Cabin Crew	Passengers	Other	Total
Fatal	0	0	0	0	0
Serious	3	0	0	0	3
Minor	0	0	0	0	0
None	0	0	0	0	0
Total	3	0	0	0	3

1.3 Damage to Aircraft

The airplane was destroyed by impact forces and a postcrash fire.

1.4 Other Damage

Trees along the wreckage path were damaged by the impact and postcrash fire. Some farm vehicles and equipment and a fence line were also damaged by the impact.

1.5 Personnel Information

The accident flight crew consisted of three reserve FedEx pilots. The accident flight was the first time all three crewmembers had flown together; however, the captain and flight engineer had flown together once previously.[21]

FedEx operates under 14 CFR Part 121, Subpart S (Flight Time Limitations: Supplemental Operations), which specifies that operators may schedule flight crew members for no more than 8 hours of flight time in a 24-hour period without a rest period within those 8 hours. Pilots must be relieved from duty for at least 24 consecutive hours at least once during any 7 consecutive days. Pilots working in three-person crews can be scheduled for no more than 18 hours of duty in a 24-hour period.[22] The three accident flight crewmembers had different flight, duty, and sleep schedules before the accident. Table 2 shows their flight schedules for the 24 hours preceding the accident. Table 3

[21] Neither the captain nor the flight engineer had a clear recall of their prior flying experience together.

[22] FedEx's scheduling practices also abide by a union bargaining agreement. This agreement is more restrictive in some respects than 14 CFR 121, Subpart S. For example, the agreement limits scheduled domestic duty periods to between 9 and 13 hours, depending on a duty period's start time.

shows the cumulative flight and duty times for the three crewmembers at the time of the accident, and figure 4 shows the three crewmembers' self-reported estimated sleep schedule during the 72 hours before the accident. All times are reported in central daylight time (the time zone in which the crewmembers were based). Sleep start and end times are estimated from the available verbal reports.

Table 2. Crew members' schedule for the 24 hours preceding the accident.

Crew member	Date	Showtime	Departure	Arrival	Block	Turn
Captain	7/26/02	0212	0324	0447	1:23	
First Officer	7/25/02	0300	0356	0645	2:49	12:17
	7/25/02	1818	1902	1935	0:33	01:22
	7/25/02		2057	2303	2:06	04:21
	7/26/02		0324	0447	1:23	
Flight Engineer	7/25/02	0236	0358	0553	1:55	00:28
	7/25/02		0626	0714	0:48	11:52
	7/25/02	1806	2139	2359	2:20	03:25
	7/26/02		0324	0447	1:23	

Table 3. Flight and duty times since the last rest period for the crew of FedEx flight 1478.

Crew Member	Flight Time	Duty Time
Captain	01:23	02:35
First Officer	04:02	10:29
Flight Engineer	03:43	10:41

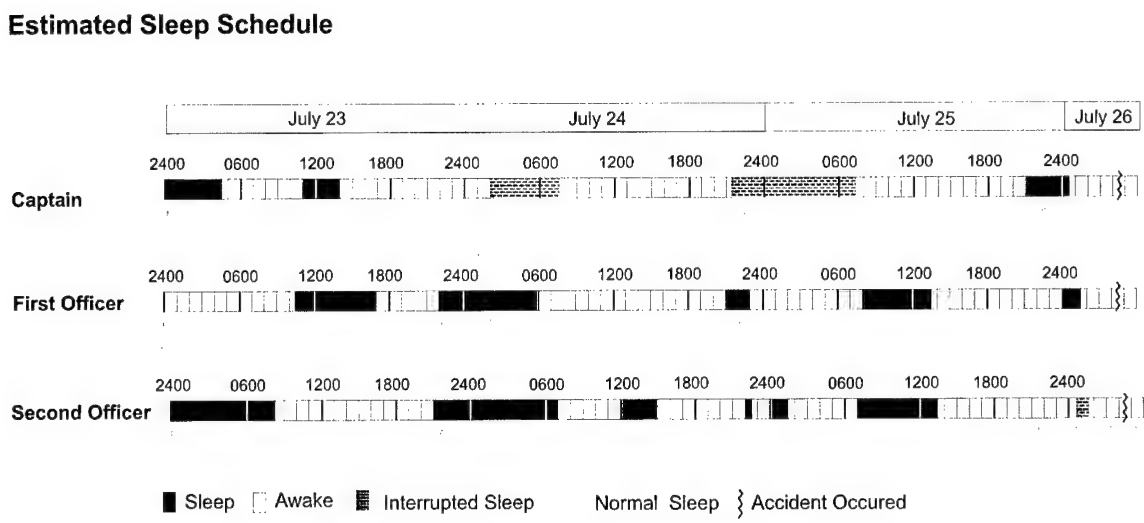

Figure 4. The three crewmembers' estimated sleep schedule during the 72 hours before the accident.

1.5.1 The Captain

The captain, age 55, was hired by FedEx on April 10, 1989. He held an airline transport pilot (ATP) certificate (issued August 6, 1999) with a multiengine land rating and a flight engineer certificate for turbojet-powered airplanes. The captain's ATP certificate indicated type ratings in the 727 (issued August 6, 1999), Cessna CE-500, and Canadair CL-600. According to FedEx training records, the captain's most recent 727 simulator proficiency check was completed on August 13, 2001; his most recent 727 line check was completed on February 7, 2002; his most recent recurrent simulator training was completed on February 15, 2002; and his most recent recurrent ground training was completed on July 22, 2002. The captain's most recent Federal Aviation Administration (FAA) first-class airman medical certificate was issued on June 17, 2002, and contained the limitation that he "must wear corrective lenses."

The captain estimated that he had flown about 13,000 to 14,000 total flight hours. According to FedEx records, at the time of the accident, the captain had about 2,754 flight hours as a 727 flight crewmember, including about 861 hours as 727 pilot-in-command, 515 hours as 727 second-in-command, and 1,378 hours as 727 flight engineer. FedEx records indicated that the captain's proficiency checks were satisfactory and that, in accordance with the company training program, he had received training in visual approaches, non-tower operations, fatigue management, and crew resource management (CRM).[23] The captain's training records indicated that he had not seen FedEx's black

[23] According to FedEx's CRM training staff, all three crewmembers would have seen a presentation on fatigue management during their baseline course for new hires. For additional information regarding FedEx's training program, see section 1.17.1.

hole[24] or CFIT avoidance training modules, which were presented during recurrent training in 1995 and 1999, because he underwent upgrade—not recurrent—training in those years.

Two FedEx first officers who flew with the captain during the week before the accident stated in postaccident interviews that he was a competent pilot who used standard procedures and callouts. One said that the captain had a "standard cockpit style with good CRM skills" and added that he was "upbeat" with a "good sense of humor." The other first officer stated that he was relatively new with FedEx (fewer than 100 hours in the 727) when he flew a 2-day, four-landing trip with the captain. He stated that the captain decided to make one landing because of foggy conditions and allowed the first officer to fly the other flight segments and landings.

The captain stated that his general health was "good," with no significant changes in the 12 months before the accident. He stated that he did not take prescription medications or smoke and that he drank alcohol only occasionally. Specifically, the captain told investigators that in the days before the accident, he did not drink alcohol or take any prescription medications.[25] The captain stated that when he was not working, he usually went to bed between 2200 and 2230 and awoke between 0700 and 0730.[26]

During postaccident interviews, the captain told investigators that at 0430 on July 23, 2002, FedEx scheduling personnel contacted him by telephone to advise him that he was assigned to fly FedEx flight 1380, from Shreveport Regional Airport (SHV), in Shreveport, Louisiana, to MEM later that day. He arrived at SHV about 1010 on July 23 and checked into a hotel, where he rested before he returned to the airport about 2030 for his assigned flight. When the captain arrived at MEM (on FedEx flight 1380) at 2353, he was released from duty and returned to his home, arriving after midnight on July 24, 2002.

The captain stated that he did not sleep well that night. He reported that he stayed awake for a "couple of hours" after he got home to take care of the family dog, which was in deteriorating health. He indicated that he slept on the couch the rest of that night so he could more easily care for the dog during the night and stated that his sleep was accordingly interrupted three times during the night. He stated that his rest period ended about 0730 on July 24 and that he engaged in routine activities throughout the day. He went to bed about 2130 that evening, again sleeping on the downstairs couch and getting up several times during the night to care for the sick dog. He stated that he awoke about 0730 on July 25, 2002, and described his sleep quality as "marginal, not really good."

Between 1800 and 1830 that day, the captain checked company scheduling using his home computer and received notification of the TLH flight assignment. He stated that he slept from about 2100 on July 25 to about 0030 on July 26; he described his sleep

[24] The term "black hole" refers to approaches conducted over unlit areas, water, or other featureless terrain. For additional information regarding FedEx's black hole guidance, see section 1.17.1.1.

[25] The captain told investigators that he had taken "a couple of [acetaminophen pills] for headaches" 72 hours before the accident.

[26] All times in this section (1.5.1) are local time at the captain's residence (central daylight time).

during that 3 1/2 hours as "pretty good" and said that he did not feel fatigued when he subsequently arrived at MEM for the accident flight.

1.5.2 The First Officer

The first officer, age 44, was hired by FedEx on October 29, 1997. He held an ATP certificate (issued October 27, 1995) with a multiengine land rating and a flight engineer certificate for turbojet-powered airplanes. The first officer's most recent recurrent 727 line check was completed on October 17, 2001; his most recent 727 simulator training was completed on December 18, 2001; his most recent 727 simulator proficiency check was completed on June 19, 2002; and his most recent recurrent ground training was completed on July 13, 2002. The first officer's most recent FAA first-class airman medical certificate was issued on October 9, 2001,[27] with no restrictions or limitations but with a Statement of Demonstrated Ability (SODA) for "defective color vision." The medical certificate and SODA were issued on the basis of the first officer's previous "operational experience."[28]

The first officer estimated that he had flown about 7,500 to 8,500 total flight hours.[29] According to FedEx records, at the time of the accident, the first officer had about 1,983 flight hours as a 727 flight crewmember, including about 526 hours as a 727 second-in-command and 1,457 hours as a 727 flight engineer. FedEx records indicated that the first officer's proficiency checks were satisfactory and that, in accordance with the company training program, he had received training in visual approaches, non-tower operations, CRM, fatigue management, and CFIT avoidance.

The first officer stated that his general health was "good," with no significant changes in the 12 months before the accident. He reported that he had called in sick July 17 through 19, 2002, because of a knee injury suffered while playing sports several weeks before.[30] He returned to his reserve duty availability on July 20. According to the first officer's wife, on July 20 and 21, the first officer engaged in routine tasks that included mowing the lawn, cleaning the pool, and walking the dog.

The first officer stated that he had not taken any medications, prescription or non-prescription, in the 3 days before the accident. He stated that he smoked about half a pack of cigarettes per day while on trips (less when he was home) and that he drank

[27] In accordance with 14 CFR Section 61.23, although the first officer's first-class medical certificate had expired, it was still valid as a second-class medical certificate.

[28] For additional information on the first officer's color vision deficiency and the SODA issued by the FAA, see section 1.13.2.

[29] The first officer was a P3 pilot in the Navy between 1979 and 1995, when he was hired by FedEx. During postaccident interviews, the first officer estimated that his total flight time included about 5,000 hours in the P3 and about 2,500 hours in the 727.

[30] A review of company records confirmed that the first officer had taken sick leave as reported. The first officer stated that he spent a lot of time with his left leg immobile during the weeks before the accident because of his knee injury and went to his primary care physician about the injury on July 22, 2002. The physician's notes from that visit stated, "injured left knee—6 weeks ago…pain behind knee…left knee no swelling or crepitus…referral for orthopedic evaluation." No orthopedic evaluation was performed before the accident.

alcohol at social events. When he was not working, he stated that he usually went to bed about 2100, fell asleep about 2200, and awoke about 0600.

Two captains who flew with the first officer in the days before the accident stated in postaccident interviews that he was personable and professional, with solid flying skills. Neither recalled any deficiencies in his performance as a flight crewmember.

The first officer stated that the reserve schedule he worked in July 2002 was difficult because his sleep-wake cycle was frequently changing between day- and night-sleep periods.[31] He told investigators that on July 23, 2002, he flew a trip that he considered very difficult—it departed MEM about 0330,[32] went to Washington Dulles International Airport in Washington, DC, then to Greater Rochester International Airport in Rochester, New York, and arrived at MEM about 1100. After the trip, he went to an apartment he leased with other FedEx pilots and went to sleep about 1130. The first officer did not recall the exact times involved but stated that he awoke in the evening and went out for dinner, then returned to the apartment and slept through the night.

The first officer reported that he awoke again on the morning of July 24 and engaged in routine activities around the apartment during the day. According to a roommate, during a conversation that morning, the first officer complained about the reserve schedule he was flying because it "reversed day and night sleeping on consecutive days." The first officer stated that he had dinner with his landlord that evening, went to bed about 2100, and slept until early morning on July 25, when he had to get up to report for duty.

The first officer arrived at MEM about 0300 on July 25 and departed on FedEx flight 134 about 0356, arriving at Winnepeg International Airport (YWG), in Manitoba, Canada, about 0645. He went to a hotel and slept for about 5 to 6 hours and had dinner before reporting for duty at YWG again about 1818. He described his quality of sleep as "no better or worse than most day sleeps." The first officer departed YWG on FedEx flight 137 about 1902 and arrived at Grand Forks International Airport (GFK), in Grand Forks, North Dakota, about 1935. Flight 137 departed GFK about 2057 and arrived at MEM about 2303.

After flight 137 landed at MEM, the first officer was notified that he was scheduled to work flight 1478 to TLH, which was scheduled to depart MEM about 0312 on July 26 (about 4 hours after flight 137 arrived). The first officer stated that he accepted the flight 1478 trip assignment after he ascertained that it did not violate existing FedEx/pilot union agreements and would not result in his exceeding flight and duty limits. He indicated that he slept for about 1 1/2 hours in a private sleep room in FedEx's crew rest facilities at MEM before he met the captain to prepare for the accident flight. He stated that, although he described that rest as "good" sleep, he did not recall "feeling

[31] The first officer told investigators that he bid the reserve schedule for the month of July to optimize his vacation time that month. He said that it had been a long time since he had flown a reserve schedule and he would rather fly a more regular (predictable) schedule.

[32] All times in this section (1.5.2) are local time in Memphis (central daylight time).

alert." A friend and roommate of the first officer's told Safety Board investigators that before the accident trip, the first officer "looked tired, like everyone else at 0330." During postaccident interviews, the accident captain said that the first officer "seemed tired, but maybe it was just his personality; he seemed not as communicative, not as alert. He may have been preoccupied."

In response to a Safety Board investigator's question during a postaccident interview, the first officer stated that he did not experience shortness of breath, cough, chest pain, or any other significant symptoms during the 24 hours before the accident. He did note some fatigue but did not consider it to be unusual given his schedule.

1.5.3 The Flight Engineer

The flight engineer, age 33, was hired by FedEx on September 3, 2001. He held an ATP certificate (issued December 14, 2000) with a multiengine land rating and a flight engineer rating for turbojet-powered airplanes. The flight engineer completed his initial ground training on September 28, 2001; his 727 initial operating experience (IOE) and line check were completed on November 8, 2001; and his most recent 727 simulator proficiency training was completed on April 8, 2002. His most recent FAA first-class airman medical certificate was issued on July 8, 2002, with no restrictions or limitations.

The flight engineer estimated that he had flown about 2,600 total flight hours. According to FedEx records, at the time of the accident, the flight engineer had about 346 flight hours as a 727 flight engineer. FedEx records indicated that the flight engineer's proficiency checks were satisfactory and that, in accordance with the company training program, he had received training in visual approaches, non-tower operations, fatigue management, and CRM. Further, postaccident discussions with the flight engineer and FedEx management personnel indicated that the company was considering the flight engineer for a check airman position.

The flight engineer stated that his general health was "good" and that there had been no changes to his health during the 12 months before the accident. He stated that he did not take prescription medications and that he drank alcohol occasionally. The flight engineer stated that when he was not working, he usually went to bed about 2230 and awoke about 0630.

The flight engineer stated that on July 23, 2002, he awoke between 0900 and 0930 and spent the day relaxing around the house because he had been experiencing back pain. He reported that he went to bed about 2200. He reported that when he awoke about 0800 on July 24, his back felt better.[33] He said he went boating with his children from about 0900 to about 1100, took a nap from about 1300 to about 1550, and engaged in routine activities at home until it was time to travel to his duty station (MEM). He arrived at the airport in Albany, New York, about 2200 to ride on a flight to MEM. He stated that he napped for about 30 minutes during the commute to MEM, arriving at MEM about 2330.[34]

[33] The flight engineer did not report any subsequent back pain before the accident.

[34] The times in the remainder of this section (1.5.3) are local time in Memphis (central daylight time).

The flight engineer stated that he slept another 90 minutes in FedEx's crew rest facility at MEM before reporting for duty at 0248 on July 25.

The flight engineer stated that FedEx flight 180 departed MEM about 0358 on July 25 and arrived at Buffalo Niagara International Airport (BUF), in Buffalo, New York, about 0558. The flight then departed BUF about 0626 and arrived at Ottawa MacDonald Cartier International Airport (YOW), Ottawa, Ontario, about 0714. The flight engineer reported that upon arrival at YOW, he checked into a hotel and slept about 6 1/2 hours. He stated that when he awoke, he was notified of his assignment to flight 1478 to TLH on July 26. As a result of his assignment to the accident flight, the flight engineer postponed a job interview for a FedEx 727 line check airman position, which was originally scheduled to occur at MEM the morning of July 26. He stated that he engaged in routine activities at the hotel and returned to YOW about 1806 on July 25 for flight 181. Flight 181 departed YOW about 2139 and arrived at MEM about 2359.

The flight engineer stated that after he arrived at MEM around midnight, he had his fingerprints taken to satisfy a new security policy, then relaxed in a recliner chair for 30 to 60 minutes. He stated that he began preparing for flight 1478 about 0135. In postaccident interviews, the captain stated that the flight engineer seemed to be alert during the accident flight.

1.6 Airplane Information

The accident airplane, N497FE, a Boeing 727-232F series airplane, was manufactured in September 1974. FedEx purchased the airplane from Delta Airlines in 1990. According to FedEx records, the accident airplane had about 37,980 total hours of operation (23,195 flight cycles)[35] at the time of the accident. The accident airplane was equipped with two Pratt & Whitney (P&W) JT8D-15 engines (engines No. 1 and No. 2) and a P&W JT8D-15A engine (engine No. 3).[36]

According to FedEx's dispatch documents for the accident flight, the airplane's estimated landing weight was 159,000 pounds, including about 44,350 pounds of cargo and about 19,000 pounds of fuel.

1.7 Meteorological Information

The National Weather Service (NWS) surface analysis chart for 0500 on July 26, 2002, depicted no fronts or other boundaries over the route of flight. The chart indicated that a ridge of high pressure was centered over central Florida. The NWS weather depiction chart for 0600 on July 26, 2002, indicated that, except for a small area of

[35] A flight cycle is one complete takeoff and landing sequence.

[36] The JT8D-15 and JT8D-15A engines are both rated at 15,500 pounds of thrust.

marginal visual flight rules conditions in north central Florida, visual flight rules conditions existed throughout the state of Florida, including the Tallahassee area.

TLH is equipped with an automated surface observation system (ASOS).[37] This weather observation system is augmented by NWS-certified weather observers under contract with the FAA. The following conditions were recorded around the time of the accident:

> TLH weather at 0453, wind from 120° at 5 knots; visibility 9 statute miles; a few clouds at 100 feet;[[38]] scattered clouds at 18,000 and 25,000 feet; temperature and dew point 22° C (72° Fahrenheit [F]); and altimeter setting 30.10 inches of Hg. Remarks: automated observation system, sea level pressure 1019.2 millibars.
>
> TLH weather at 0553, wind calm; visibility 8 statute miles; a few clouds at 100 feet; scattered clouds at 15,000 and 25,000 feet; temperature and dew point 22° C (72° F); and altimeter setting 30.10 inches of Hg. Remarks: automated observation system, sea level pressure 1019.2 millibars.
>
> TLH weather at 0653, wind calm; visibility 9 statute miles; a few clouds at 100 feet; scattered clouds at 1,500, 15,000 and 25,000 feet; temperature and dew point 22° C (72° F); and altimeter setting 30.10 inches of Hg. Remarks: automated observation system, sea level pressure 1019.2 millibars, sector visibility from the southwest through northwest quadrants 1/2 mile, cumulonimbus clouds in the distance towards the southeast and southwest, smoke scattered at 1,500 feet, smoke plume over the approach end of runway 9.

The weather forecast for TLH that FedEx provided the pilots indicated that between 2300 and 0459, ceilings would be above 2,000 feet, visibility greater than 3 statute miles, and winds less than 10 knots. The FedEx forecasts between 0500 and 0959 indicated, "sky partially obscured, visibility 3 miles in mist, with occasional scattered clouds at 500 feet and visibility 1 mile in mist." There were no in-flight weather advisories for around the time of the accident.

The astronomical data for July 26, 2002, indicated that the sun was more than 10° below the horizon at the time of the accident; civil twilight began at 0626, and sunrise occurred at 0652. At the time of the accident, the moon was located about 31° above the

[37] The ASOS continuously measures wind, visibility, precipitation and obstructions to vision, cloud height, sky cover, temperature, dew point, and altimeter setting.

[38] The weather observer on duty at TLH when the accident occurred, reported that, when he completed his observation minutes before the accident, he saw some very thin stratus clouds between about 25 feet agl and treetop level (about 60 feet agl) in the wooded area west of the airport near the midpoint of runway 18/36. He stated that these light stratus clouds were north of the accident site. The observer stated that he saw no restriction to visibility near the accident site. (The observer was located on the airport's south ramp, about 1/4 mile east of the tree line and immediately north of runway 9/27, near the fire station, which is shown on figure 5 in section 1.10.) Although the captain reported that there were "a few little wispy…clouds or mist" as they neared the runway, the three pilots stated that there were no clouds obscuring their view of the runway during their approach.

horizon and was behind and to the right of the accident airplane's approach course. Records indicate that there was 95 percent illumination from the moon at the time of the accident.

1.8 Aids to Navigation

No difficulties with the navigational aids were known or reported.

1.9 Communications

No difficulties with communications were known or reported.

1.10 Airport Information

TLH is located about 4 miles southwest of downtown Tallahassee, Florida. The official airport elevation is 81 feet. The TLH air traffic control tower (ATCT) operates part time and is closed daily between 2300 and 0600. Control of the airspace that is normally delegated to TLH terminal radar approach control (TRACON) and ATCT reverts to Jacksonville ARTCC when the TLH ATCT is closed.

The airport has two perpendicular runways. Runway 18/36 is 6,076 feet long and 150 feet wide and is located along the west side of the field. Runway 9/27 is 8,000 feet long and 150 feet wide and is located along the south side of the field (see figure 5). Runways 36 and 27 have ILS approaches, and runways 9 and 18 have visual approaches. The airport layout plan indicated that the terrain west of the airport was national forest property and was densely wooded.

As previously indicated, at the time of the accident, runway 18/36 was closed for construction; Notice to Airmen 02-47 was issued on July 19, 2002, for the closure. The accident airplane was on the visual approach to runway 9. Runway 9 has an elevation of 61.2 feet msl at the approach end and 49.0 feet msl at the departure end, with a maximum elevation of 70.5 feet msl about 2,325 feet from the approach end. There is a 0.4 percent upslope gradient from the approach end of runway 9 to the runway's maximum elevation (slightly less than the first one-third of the runway).[39]

[39] FAA Advisory Circular (AC) 150/5300-13, titled "Airport Design," states that "[t]he maximum allowable longitudinal runway gradient at airports with Approach Categories C and D, is plus or minus 1.5 percent; however, the gradient may not exceed 0.8 percent in the first and/or last quarter of the runway length."

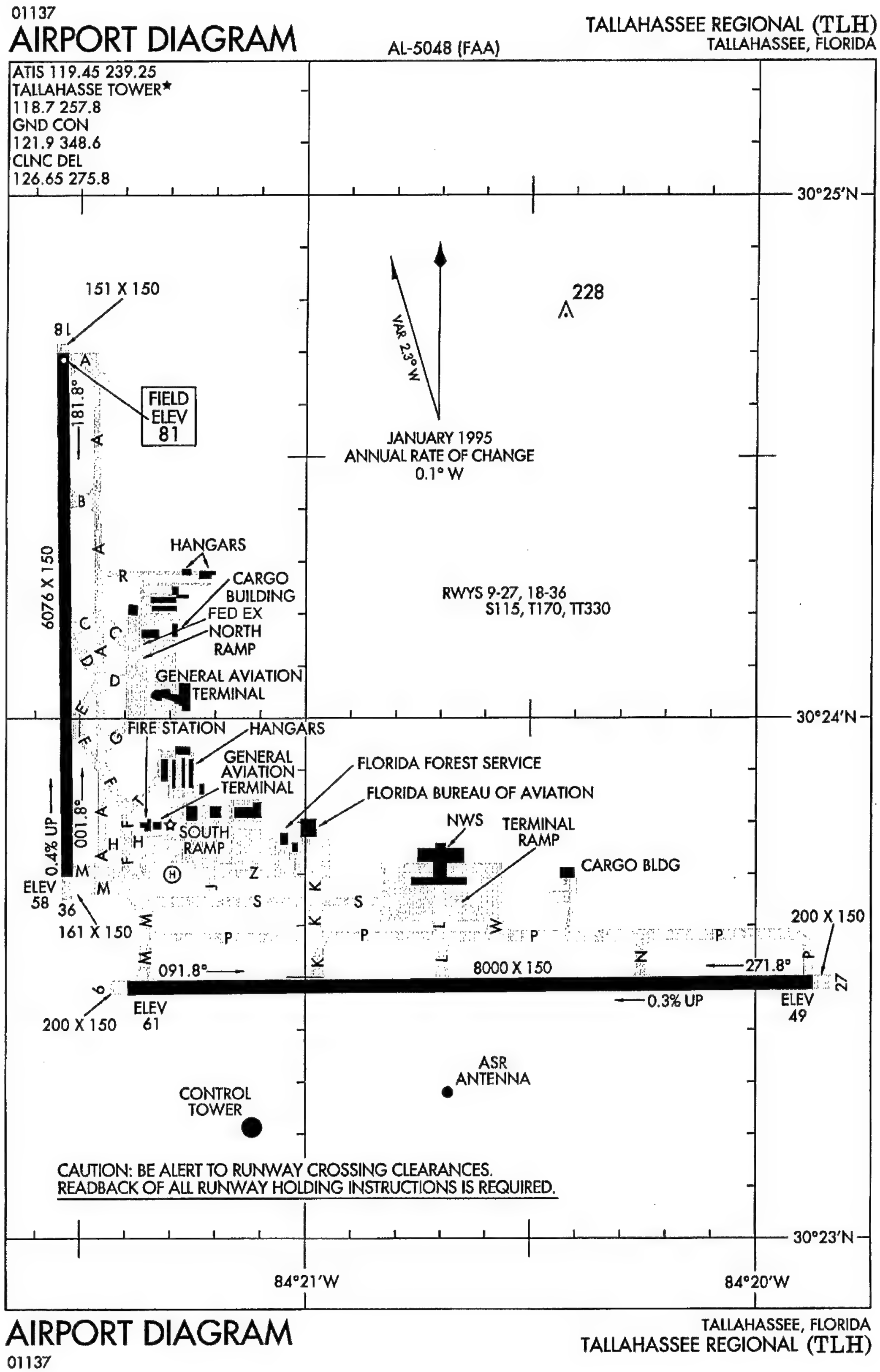

Figure 5. TLH airport diagram.

1.10.1 Airport/Approach Charts

The Jeppesen approach charts for TLH included a precision (that is, ILS) approach chart for runway 27, but no precision approach for runway 9. The chart for runway 9 depicted a nonprecision radar approach for which TLH TRACON (or Jacksonville ARTCC, depending on the time of day) would vector the airplane to a final approach course to runway 9 using airport surveillance radar.[40] The first officer's landing briefings for runways 27 and 9 reflected the information available on those approach charts.

FedEx provided its flight crews with two internally generated airport chart pages to augment the published Jeppesen airport and approach charts for TLH. These FedEx pages (10-10 and 10-10A) contained information pertinent to FedEx operations at TLH, including airport-specific precautions, ATCT hours of operation, noise abatement procedures, weather information, emergency contact information/procedures, and runway lighting/traffic advisory information for hours of non-tower operation. The FedEx TLH chart pages also characterized the CFIT risk at TLH as moderate,[41] with page 10-10A stating, "Local ATC and radar coverage unavailable at certain times. ILS not installed in all directions, potential nonprecision approach. The airport has no published departure procedure."

1.10.2 Runway 9 Lighting

Runway 9 was equipped with high intensity runway lights, in-pavement runway centerline lights, and runway end identifier lights. A four-box PAPI light system was located on the left side of runway 9 to provide lighted signal glidepath guidance relative to the published 3° glidepath to the runway's touchdown zone. The runway inspection log for July 25, 2002, indicated that the runway lighting was operational.

When the TLH ATCT was open, air traffic controllers controlled the airport/runway lighting from the tower cab. However, when the TLH ATCT was closed, the airport's lights (with the exception of the rotating beacon) were off unless activated by a pilot keying the airplane microphone with the airplane's communication radio tuned to the common traffic advisory frequency (CTAF). During the activation process, the airport lighting systems, including runway edge lights, taxiway lights, and the PAPI, activate over a period of a few seconds. Once activated, the airport lights remain on for 15 minutes. The airport lighting activation log indicated that, on the day of the accident, the lights were

[40] Although the TLH TRACON was closed, Jacksonville ARTCC could have provided the pilots of flight 1478 with the necessary vectors; however, when the pilots reported that they had TLH in sight, they were cleared for the visual approach.

[41] For additional information regarding FedEx's classification of CFIT risk at airports, see section 1.17.1.1.

activated about 0534:26, and all lights were on by about 0534:31.[42] According to CVR and airport lighting activation log evidence, the runway lights were activated on medium intensity.

1.10.2.1 Runway 9 PAPI Lighting System

The PAPI lighting system installed on the left side of the approach end of runway 9 was an ADB, ALNACO, Inc. (a subsidiary of Siemens Airfield Solutions) model L-880, style A, and consisted of four identical light boxes mounted along a line perpendicular to the runway centerline about 1,000 feet from the approach end of the runway. Each of the four boxes contained two 200-watt lamps and optical apparatus to split the lamp beams horizontally into red (lower) and white (upper) beams. The lamps in each of the four light boxes were positioned so that each box projected a signal at a prescribed angle above the horizon, relative to a 3° glidepath.[43] An on-glidepath signal is represented by the two left-side boxes showing white lights and the two right-side boxes showing red lights. If an airplane is beneath the glidepath, more red lights would be visible to the pilots; if an airplane is above the glidepath, more white lights would be visible. Figure 6 shows PAPI indications from various approach path angles.

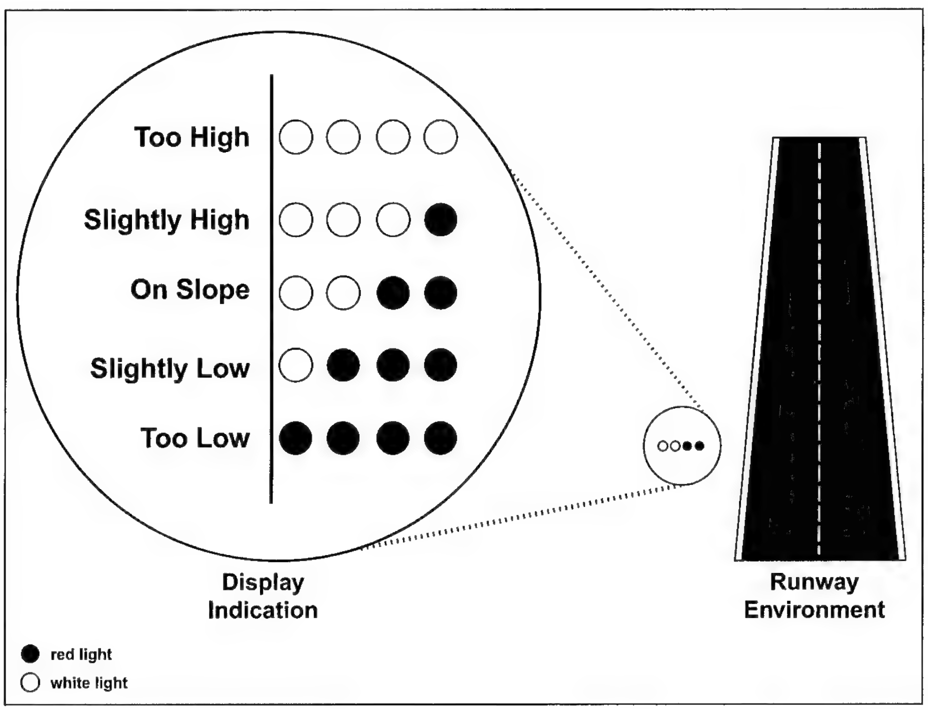

Figure 6. PAPI indications from various approach path angles.

[42] Examination of the computer that controlled the airport's lighting log indicated that the computer time had not been adjusted for daylight savings time and was also 3 minutes and 16 seconds ahead of the time displayed on a handheld global positioning system receiver. Applying the 56 minute, 44 second difference as a correction factor to the time indicated on the activation log resulted in an airport lighting activation time of about 0534:26; all lights were activated by about 0534:31.

[43] According to the manufacturer, a narrow band of pink can normally be seen briefly by a pilot when an airplane transitions between the PAPI unit's white and red beams during its descent.

When activated, the TLH PAPI lights are automatically regulated to operate at 100 percent intensity during daylight hours and at 20 percent intensity during nighttime (regardless of the selected intensity of other runway/airport lights), consistent with FAA Advisory Circular (AC) 150/5345-28D. According to the manufacturer, the red light filters in the ADB PAPI system conform to Military Standard C-L5050 for "aviation red" coloring, as outlined in the AC. The filters are designed to retain accurate coloring for the life of the PAPI system.

The PAPI system for runway 9 at TLH was installed in 1996. According to electrical technicians at TLH, the runway 9 PAPI system had been checked with a manufacturer-provided and FAA-approved sighting tool "five to six times" since the system was installed, with no improper alignment observed.[44] (The FAA does not require certification of an airport's PAPI lighting system if an FAA-approved aiming device is used to maintain the system.)

1.10.2.2 Postaccident Flight and Ground Evaluations of the Runway 9 PAPI System

About 1300, on July 29, 2002, the FAA conducted a flight evaluation of the runway 9 PAPI system. According to the FAA's flight inspection report, the PAPI's glideslope angle and obstacle clearance were satisfactory. The flight inspection report stated, "this evaluation was conducted by flying one approach with on-path indications and one approach at an angle consistent with the [fourth of four red boxes] just turning red. On both approaches, the glidepath flown was well clear of the terrain and obstacles in the approach zone."

An additional postaccident flight check of the runway 9 PAPI system was conducted between 0800 and 0900 on August 6, 2002.[45] The resultant flight inspection report indicated that the PAPI's intensity, glideslope angle, angular coverage, and focus and adjustments were satisfactory and stated, "found average PAPI angle at 2.90 degrees and angular coverage satisfactory."[46]

Despite the two satisfactory flight inspections, TLH airport personnel classified the PAPI lighting system for runway 9 as out of service as a precaution, and no adjustments to the system were allowed until after the technical inspection and measurement of the PAPI light units. About 1330, on October 10, 2002, the TLH runway 9 PAPI light units were inspected using the aiming tool provided by the manufacturer in accordance with the manufacturer's instruction manual. The observed

[44] No record or log of these inspections was maintained at TLH.

[45] This preliminary flight inspection indicated that the PAPI appeared to be operating normally; however, TLH was unable to provide airport survey data at the time. Therefore, the FAA performed a second flight inspection after it obtained the TLH airport survey data necessary to calculate precise PAPI angles for the runway.

[46] FAA Order 8200.1, "Flight Inspection Handbook," allows ± 0.2° variation from the 3° glidepath between flight inspection measurements and ground settings.

settings for the PAPI's four light units were consistent with the manufacturer's recommended settings for a standard PAPI installation.

1.10.2.3 Effects of Contamination on PAPI Light Lenses

According to a research study that the FAA conducted to assess the attributes of PAPI systems,[47] "PAPI units tended to form condensation on the exposed frontal surface of the lenses during high humidity conditions while the system was de-energized. Upon activation, diffusion and mixing of the projected colors created a broad 'pink' signal, which could not be easily interpreted." The FAA also found that condensate on the PAPI lenses began to evaporate as soon as the lamps were energized. (The rate at which evaporation occurred varied based on the amount of condensate, ambient temperature, relative humidity, and intensity of PAPI lamps.)[48] The FAA's report concluded that the transient false signals could be eliminated by: 1) energizing the system continuously; 2) energizing the system at least 30 minutes before in-flight use; and/or 3) installing heaters in close proximity to the lenses.[49]

During a telephone interview conducted on August 16, 2002, a representative of the PAPI manufacturer stated that the company was aware of an Aerodrome Safety Circular (No. 98-2002) issued by Transport Canada that similarly concluded that ice, dew, or frost on the PAPI front lens surface can affect the projected PAPI signal, producing false slope indications. The Transport Canada circular also recommended that airport operators operate the PAPI continuously or provide an adequate PAPI system "warm up" period before use to prevent a false signal due to PAPI lens contamination. The PAPI manufacturer offers optional heating units that can be installed in the light units; however, according to the representative, "customers do not often request them." The manufacturer's representative emphasized that the units produce substantial heat and will "burn off any traces of dew or frost within minutes." He stated that the manufacturer recommends that the lighting units be activated a few minutes before using the system.

On December 12, 2002, the FAA issued CertAlert Number 02-08, "PAPI Operation," which advised that 14 CFR Part 139-certificated airport operators should "rewire pilot controlled PAPI systems to make them operate continuously in order to preclude environmental contamination of the lenses." The TLH PAPI lights were subsequently rewired in accordance with the CertAlert.

The Safety Board notes that the National Air Traffic Controllers Association (NATCA) submission on this accident stated that there was a "high level of physical particle contamination" on the runway 9 PAPI boxes at TLH. However, investigators who

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[47] For additional information, see the FAA's final report on this study, U.S. Department of Transportation, Federal Aviation Administration, *Evaluation of Precision Approach Path Indicator (PAPI)* DOT/FAA-RD-82/85, Bret Castle: FAA, 1983.

[48] The Safety Board notes that the TLH weather observations around the time of the accident indicated matching temperatures and dew points (conditions conducive to the formation of dew and/or fog). However, there were no (official or unofficial) reports of dew or fog in the area at the time of the accident.

[49] According to the FAA's report, the suggested 30-minute warm-up period was not based on any scientific study but, rather, reflected a conservative estimate for reliable PAPI use.

examined the PAPI boxes during the on-scene investigation (including the NATCA representative and other members of the investigative team) noted no such contamination, and the investigation developed no evidence to support this contention.

1.11 Flight Recorders

1.11.1 Cockpit Voice Recorder

The CVR installed on the accident airplane was a Fairchild[50] model A100, serial number (S/N) 4549, magnetic tape CVR. The exterior dust cover was sooted; however, no mechanical damage was observed and the tape was successfully played back. The CVR recording consisted of four channels of good quality[51] audio information: one channel contained audio information recorded by the cockpit area microphone, and the other three channels contained audio information recorded through the radio/intercom audio panels at the captain, first officer, and flight engineer positions. The CVR records incoming and outgoing radio transmissions and "hot" microphone[52] signals from the pilots' headsets through these audio panels.

The recording began about 0505:14 and ended at 0537:26.2, after it recorded a series of crunching sounds. A transcript was prepared of the entire 32-minute, 12-second recording. See appendix B for a complete transcript of the CVR recording.

1.11.1.1 CVR Sound Study

During the review and transcription of the CVR, investigators noted unusual breathing sounds on the first officer's CVR channel (as captured by his "hot," or boom, microphone) during the last 20 minutes of the CVR recording.[53] The Safety Board conducted a study to document, characterize, and measure the breathing sounds recorded on the first officer's channel. The Board's study and associated research indicated that the first officer's breathing rate during that 20-minute period (on average, 30 breaths per

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[50] Fairchild is now known as L^3 Communications.

[51] The Safety Board uses the following categories to classify the levels of CVR recording quality: excellent, good, fair, poor, and unusable. A good quality recording is one in which most of the crew conversations could be accurately and easily understood. The transcript that was developed may indicate several words or phrases that were not intelligible. Any loss in the transcript can be attributed to minor technical deficiencies or momentary dropouts in the recording system or to a large number of simultaneous cockpit/radio transmissions that obscure each other.

[52] A "hot" microphone is always on and is being recorded by the CVR, whether or not a radio transmission is being made. According to the CVR Group Chairman's Factual Report, it appeared that hot microphones were used by all three crewmembers throughout most of the recording.

[53] Although it is somewhat unusual to hear breathing on a CVR recording, it is not unprecedented; Safety Board investigators have noted sounds similar to breaths on CVR transcripts before. For example, see National Transportation Safety Board, *USAir Flight 427, Boeing 737-300, N513AU, Uncontrolled Descent and Collision With Terrain, Near Aliquippa, Pennsylvania, September 8, 1994,* Aircraft Accident Report NTSB/AAR-99/01 (Washington, DC: NTSB, 1999).

minute [bpm]) was higher than normal (about 12 to 20 bpm, according to some research[54]) but was within the range of normal breathing for studies involving high stress situations.[55]

The Safety Board's CVR sound study also revealed several instances of a pattern in the first officer's breathing that was characterized by a series of breath sounds with progressively increasing relative loudness (and in at least one case, duration) that were followed by a series of breath sounds with progressively decreasing relative loudness. It was not possible to determine whether this effect was the result of actual changes in depth of breathing or some other phenomenon.[56]

1.11.2 Flight Data Recorder

The FDR was a solid state Universal Flight Data Recorder, part number 980-4120-KXUS, S/N 2343, that recorded 60 parameters of airplane flight information in a digital format using solid-state flash memory. The FDR was recovered in good condition, and more than 27 hours of data were successfully downloaded. The recorded parameters included altitude; airspeed; magnetic heading; control column, control wheel, and rudder pedal position; left aileron, horizontal stabilizer, and right and left elevator and rudder surface positions; trailing- and leading-edge flap and slat positions on both wings; vertical, lateral, and longitudinal acceleration; pitch and roll attitude; and EPR for all three engines.

1.12 Wreckage Recovery and Documentation Information

The wreckage path extended over a distance of about 2,094 feet, from the airplane's first impact with trees about 3,650 feet from the approach end of runway 9 to the site where the main airplane wreckage (fuselage, left wing, and tail section) came to rest, about 1,556 feet west-southwest of the approach end of runway 9. The airplane came to rest oriented on a heading of 260° (about 170° from the easterly inbound course for runway 9). The airplane first impacted trees about 50 feet above the ground. A swath of

[54] J.A.Veltman, "A Comparative Study of Psychophysiological Reactions During Simulator and Real Flight," *Int J Aviat Psychol* Vol. 12, No. 1 (Jan 2002): 33-48. The maximum breathing rate observed in this study was 21 bpm. Other research data showed the average breathing rate of F-4 pilots during air-to-ground missions was between 17 and 19 bpm. See also, R.L. DeHart, *Fundamentals of Aerospace Medicine*, 2nd ed. (Baltimore, MD: Williams & Wilkins, 1996).

[55] M. Schedlowski and U.Tewes, "Physiological Arousal and Perception of Bodily State During Parachute Jumping," *Psychophysiology* The Society for Psychophysiological Research, Inc. Vol. 29, No. 1 (1992): 95-103.

[56] Research has shown that variations in depth of breathing similar in timing and shape to those observed in the Safety Board's sound study were associated with hypoxia. See (a) T.S. Chadha, S. Birch, and M.A. Sackner, "Periodic Breathing Triggered by Hypoxia in Normal Awake Adults. Modification by Naloxone," *Chest* Vol. 88, No. 1 (Jul 1985): 16-23. (b) K. Fumimoto, Y. Matsuzawa, K. Hirai, and others, "Irregular Nocturnal Breathing Patterns at High Altitude In Subjects Susceptible to High-Altitude Pulmonary Edema (HAPE): A Preliminary Study," *Aviation, Space, and Environmental Medicine Journal* Vol. 60, No. 8 (Aug 1989): 786-91. Also, for additional information on hypoxia, see section 1.18.1.

broken trees continued to the edge of the wooded area (about 1,130 feet from the initial impact), where the trees on the right and left sides of the swath were broken at 7.9 feet and 31.7 feet, respectively. (Figure 7 shows the swath of damaged trees, looking from east to west, with the first ground scars and airplane wreckage in the foreground.) Pieces of the right wing (including the right wing leading-edge flap, trailing-edge flap, wing tip, strobe light, flap jack screws, and slat tracks) were located in the wooded area.

Figure 7. A swath of trees damaged by impact with FedEx flight 1478.

The first evidence of ground impact was located near the edge of the wooded area, about 170 feet from open terrain. The ground scars continued in the open terrain, increasing in width from about 29 feet near the edge of the trees to about 120 feet near the main wreckage. There was evidence of fire along the wreckage path for about 800 feet leading to the main wreckage, which was destroyed by impact and postimpact fire.

The forward fuselage was relatively intact but exhibited impact and fire damage, some of which was severe. The cockpit was severely damaged by fire, with melted and resolidified aluminum draped over the control wheels and pilot seats and the instrument panels destroyed. The lower overhead lighting panel was severely burned and damaged; however, examination revealed that the left and right inboard landing light switches appeared to be in the down, or "on," position, and the left and right outboard landing light switches appeared to be in the up, or "off," position. The taxi, navigation, and strobe light switches all appeared to be in the down, or "on," position.[57] The five left-side cockpit

[57] According to the amplified before landing checklist contained in FedEx's 727 CFM, pilots should "use inboard and outboard landing lights, runway turn off lights, and taxi lights for runway illumination during landing. If weather conditions dictate, turning landing lights on may be delayed until [the flying pilot] calls for them."

windows exhibited fire damage but were intact; the left-side sliding window was open. One of the five right-side cockpit windows was intact but exhibited fire damage; the other four right-side windows were missing. A portion of the nose landing gear was separated from the fuselage and was found about 320 feet northeast of the main wreckage.

The top of the fuselage over the cargo area was missing and believed to have been consumed by fire; adjacent fuselage side walls exhibited severe fire damage. The left wing remained attached to the fuselage and exhibited localized impact and fire damage. The right wing had separated and was severely fragmented, with pieces located throughout the wreckage path; most separated pieces of the right wing revealed no evidence of fire. One section of the right wing that exhibited severe fire damage was located near the main wreckage and included portions of the inboard upper and lower wing skins. A large section of the wing rear spar from the center wing tank was also found with fire damage in this area. The left main landing gear was found in the down and locked position and exhibited some soot and fire damage. The right main landing gear was separated from its attachment points and was located next to the right side of the fuselage; it showed evidence of impact and fire damage.

The aft fuselage remained attached to the rest of the fuselage but exhibited severe fire and impact damage. The vertical stabilizer, rudder, and rudder trim tab were heavily sooted but remained attached to each other and the fuselage; these surfaces exhibited no evidence of impact damage. The left horizontal stabilizer, elevator, and elevator trim tab remained attached to each other and the vertical stabilizer; they were sooted and exhibited some impact damage. The right horizontal stabilizer, elevator, and elevator trim tab exhibited evidence of severe impact damage, and the outboard sections of these surfaces were separated from the main wreckage and located in the wooded area of the wreckage path. The separated sections of these surfaces showed impact damage but no fire damage, whereas those sections that remained with the aft fuselage exhibited fire and impact damage.

The No. 1 engine remained attached to the fuselage, and the No. 2 and No. 3 engines were separated from the fuselage. Examination of the three engines revealed no evidence of preimpact malfunction; all three engines exhibited damage consistent with operation at impact.

The impact- and fire-related damage to the airplane precluded the determination of flight control continuity. However, the Safety Board's examination of the CVR and FDR information, the wreckage, and recovered cargo revealed no evidence of flight control or other system or structure malfunction before the airplane impacted the trees. Further, there was no evidence of preimpact smoke, fire, or fumes. The recovered hazardous materials packaging showed external sooting.

1.13 Medical and Pathological Information

1.13.1 Toxicological Information

Toxicological samples obtained from the captain, first officer, and flight engineer after they were admitted to the hospital emergency room were sent to the FAA's Toxicology and Accident Research Laboratory in Oklahoma City, Oklahoma, for examination. The blood specimen collected from the captain tested negative for ethanol and a wide range of drugs, including drugs of abuse;[58] however, the urine specimen collected from the captain tested positive for morphine (1.306 ug/ml) and acetaminophen (15.57 ug/ml). A review of emergency room hospital records indicated that the captain was administered morphine intravenously about 0640 as part of his postaccident medical treatment and that the urine specimen was collected from the captain about 0714. The blood and urine specimens collected from the first officer and flight engineer tested negative for ethanol and a wide range of drugs, including all drugs of abuse.

1.13.2 First Officer's Color Vision Deficiency

1.13.2.1 First Officer's Color Vision Deficiency History

According to the first officer's annual Navy medical reports, the first officer consistently demonstrated 20/20 or better near and distant visual acuity in both eyes without correction during his 16 years of Naval service. The records indicated that color vision testing was performed in conjunction with the pilot's annual medical examinations by means of the Farnsworth Lantern (FALANT)[59] test (the Navy's primary color vision screen) and that the first officer consistently passed.[60]

The first officer told investigators that he never had a color vision problem in the Navy. However, during a July 24, 1995, evaluation for an FAA medical certificate,[61] the first officer did not pass a color vision screen that was conducted using pseudoisochromatic

[58] The drugs tested in the postaccident analysis include (but are not limited to) marijuana, cocaine, opiates, phencyclidine, amphetamines, benzodiazapines, barbiturates, antidepressants, antihistamines, meprobamate, and methaqualone.

[59] The FALANT is an FAA-acceptable color vision screening test for FAA pilot certification that is intended to identify (for exclusion) people with significant red-green color vision deficiency who are unable to name aviation (and other) signal lights correctly, while "passing" people with mild red-green vision deficiency. In this test, the applicant is asked to identify the color (red, green, or white) of two lights projected by the FALANT machine. The examinee must identify nine different light pairings.

[60] The first officer's military medical records indicate that he passed the Navy's color vision test 13 times during his military career—10 times with a documented score of 9/9, 2 times with no documented score, and 1 time with the documented remark "passed-by history."

[61] According to 14 CFR Section 67.103(c), the eye standards for a first-class medical certificate include the "ability to perceive those colors necessary for the safe performance of airman duties."

plates (PIP).[62] The FAA-designated medical examiner who conducted the evaluation contacted the FAA's Regional Flight Surgeon for advice and was told to issue the first officer's medical certificate for use with a SODA for the color vision deficiency. In a July 25, 1995, letter to the Regional Flight Surgeon documenting their discussion, the medical examiner stated that the results of the first officer's color vision screen indicated "a color vision loss on pseudoisochromatic plates, missing numbers 3, 4, 5, and 6. This suggests mild red-green defect. Per your instructions I gave him his certificate....Please notify me about any SODA number that he is issued." The FAA issued a SODA on August 1, 1995, and, in a same-day letter to the first officer, the Regional Flight Surgeon stated, "based on your operational experience, I have determined that you are eligible for a first-class medical along with [a SODA] for defective color vision." When the first officer obtained his most recent first-class medical, dated October 9, 2001, he was again issued the certificate with a SODA for the color vision deficiency.

As a result of the Safety Board's postaccident inquiry, on September 5, 2002, the FAA's New England Regional Flight Surgeon wrote a letter to the FAA's Recommendation and Quality Assurance Division (AAI-200) further describing the circumstances under which the first officer's medical certificate and SODA were issued in July/August 1995. The letter stated that the medical examiner subsequently described the first officer's flight experience and indicated that, although the first officer had not previously failed a color vision test, he had failed the PIP color vision test on the day of his evaluation. After some discussion, the Regional Flight Surgeon advised the medical examiner to issue a medical certificate with a SODA for the color vision deficiency to the first officer. According to the September 2002 letter, a review of FAA computer records indicated that an FAA medical examination of the first officer dated June 20, 1986,[63] during which the FALANT color vision screen was administered, resulted in an indication of normal color vision. The letter indicated that, based on the first officer's previous medical examination results and "operational experience as a Naval aviator...a decision was made to issue a SODA."

During postaccident interviews, the first officer's wife told investigators that she vaguely remembered hearing about her husband's color vision deficiency. She stated "I recall this was way back when he was in training for the Navy when this came up. I think it was like a blue/green problem...he was given a waiver for it." When asked if the first officer's color vision deficiency ever affected anything in his daily life (for example, did she or her daughters ever have to help him match articles of clothing), the first officer's

[62] PIPs used by the FAA for aeromedical certification are cards with colored spots or patterns that are selected and arranged such that individuals with normal color vision will see a number or figure. The examiner holds the plates about 30 inches in front of the applicant, who then has 3 seconds to identify the figure. There are several FAA-approved versions of the PIP color vision test, ranging from 14 to 38 plates and with different success criteria. For example, in the case of the 14-plate edition of the Ishihara PIP, no more than five errors are allowed on plates 1 through 11.

[63] Upon request after this accident, the Safety Board received the first officer's airman records from the FAA's Civil Aerospace Medical Institute (the FAA's national repository for airman medical certification data); these records showed consistent, periodic medical examinations dating from the first officer's 1995 application for an FAA medical certificate to his most recent preaccident medical examination. Records maintained at the FAA's Regional Office included evidence of the earlier (1986) medical examination.

wife responded, "no." Further, the first officer told investigators that he never experienced any difficulty distinguishing red and white on PAPI or VASI (visual approach slope indicator) lights.

1.13.2.2 The FAA's SODA Issuance and Requirements

Title 14 CFR Section 67.401(a) states the following regarding special issuance of a medical certificate:

> At the discretion of the [FAA's] Federal Air Surgeon, an authorization for Special Issuance of a Medical Certificate (Authorization), valid for a specified period, may be granted to a person who does not meet the provisions...of this part if the person shows to the satisfaction of the Federal Air Surgeon that the duties authorized by the class of medical certificate applied for can be performed without endangering public safety during the period in which the Authorization would be in force. The Federal Air Surgeon may authorize a special medical flight test, practical test, or medical evaluation for this purpose.

Section 67.401(b) further states the following regarding issuance of a SODA:

> At the discretion of the Federal Air Surgeon, a Statement of Demonstrated Ability (SODA) may be granted, instead of an Authorization, to a person whose disqualifying condition is static or nonprogressive and who has been found capable of performing airman duties without endangering public safety. A SODA does not expire and authorizes a designated aviation medical examiner to issue a medical certificate of a specified class if the examiner finds that the condition described on its face has not adversely changed.

According to Section 67.401(c):

> In granting an Authorization or SODA, the Federal Air Surgeon may consider the person's operational experience and any medical facts that may affect the ability of the person to perform airman duties including—
>
> (1) The combined effect on the person of failure to meet more than one requirement of this part; and
> (2) The prognosis derived from professional consideration of all available information regarding the person.

According to the Guide for Aviation Medical Examiners (GAME) in effect in 1995 (when the first officer failed the PIP color vision screening test), "If an applicant fails to meet the color vision standard as interpreted above but is otherwise qualified, the Examiner may issue a medical certificate bearing the limitation: "Not valid for night flying or by color signal control." The GAME also states the following regarding the process by which a color-vision-deficient applicant may be certificated:

> An applicant who holds a medical certificate bearing a color vision limitation may request reevaluation or special issuance. This request should be in writing and should be directed to the Aeromedical Certification Division, AAM-300. If the applicant can perform the color vision tasks, the FAA will issue a medical

certificate without limitation with a SODA. Demonstrating the ability to perform color vision tasks appropriate to the certificate applied for may entail a medical flight test or a signal light test. If a signal light test or medical flight test is required, the FAA will authorize the test. The signal light test may be given at any time during flight training. The medical flight test is most often required when an airman with borderline color vision wishes to upgrade a medical certificate."

Chapter 27 of FAA Order 8700.1, "General Aviation Operations Inspector's Handbook," instructs FAA personnel to conduct the practical color signal light test, in part, as follows:

1) Accompany the applicant to an area approximately 1,000 feet from the light operator.
   a) Instruct the applicant to respond to each light by stating the light color shown within the 5-second interval when the light is displayed.
   b) Signal the light operator to begin the procedure.
   c) ...record the color displayed and the applicant's response.
   d) After a 3-minute interval, repeat the procedure until all three colors are shown.
2) Accompany the applicant to an area approximately 1,500 feet from the light operator and repeat the procedures outlined above. Be sure that all three colors have been displayed before completing the test.
3) Do not give the applicant any indication of the accuracy of his or her readings during the test. If the applicant does not call each color correctly while the light is being shown, the applicant has failed; however, continue until the test is completed.
4) An applicant who fails the signal light test during daylight hours may repeat the test at night.
5) Should the applicant fail the signal light test during daylight hours and at night, the restriction, "Not valid for flight by color signal control," must be placed on both the replacement medical certificate and the new SODA.

Chapter 27 of FAA Order 8700.1 also states that an applicant who fails a color vision screening test must "demonstrate...the ability to read aeronautical charts, including print in various sizes, colors, and typefaces...the ability to read aviation instruments, particularly those with colored limitation marks, especially marker beacon lights, warning lights...the...ability to see colored lights of other aircraft in the vicinity, runway approach lights...all color signal lights normally used in air traffic control."[64]

[64] According to FAA records, "a light gun signal test was administered to [the first officer] on February 24, 2004, in accordance with FAA Order 8700.1...[The first officer] successfully completed the test." On the basis of his successful completion of this test, the first officer obtained a medical certificate without reference to color vision deficiency.

FAA database records indicate that the following SODAs were issued in 2002 (the most recent year for which data are available):

- 1,576 first-class medical certificates were issued to applicants who failed an initial FAA-acceptable color vision screening test[65] and subsequently successfully completed a practical color signal light test; 104 first-class medical certificates were issued to applicants who failed an initial FAA-acceptable color vision screening test and subsequently passed an alternate FAA-acceptable color vision screening test; 13 first-class medical certificates with restrictions were issued to applicants who failed an initial FAA-acceptable color vision screening test and passed a subsequent practical color signal light test; and 24 first-class medical certificates with restrictions were issued to applicants who failed an initial FAA-acceptable color vision screening test and a subsequent practical color signal light test administered in the daytime, then passed a subsequent practical color signal light test administered at night.
- 984 second-class medical certificates were issued to applicants who failed an initial FAA-acceptable color vision screening test and subsequently successfully completed a practical color signal light test; 84 second-class medical certificates were issued to applicants who failed an initial FAA-acceptable color vision screening test and subsequently passed an alternate FAA-acceptable color vision screening test; 37 second-class medical certificates with restrictions were issued to applicants who failed an initial FAA-acceptable color vision screening test and a subsequent practical color signal light test; and 36 second-class medical certificates with restrictions were issued to applicants who failed an initial FAA-acceptable color vision screening test and a subsequent practical color signal light test administered in the daytime, then passed a subsequent practical color signal light test administered at night.
- 3,851 third-class medical certificates were issued to applicants who failed an initial FAA-acceptable color vision screening test and subsequently successfully completed a practical color signal light test; 194 third-class medical certificates were issued to applicants who failed an initial FAA-acceptable color vision screening test and subsequently passed an alternate FAA-acceptable color vision screening test; 246 third-class medical certificates with restrictions were issued to applicants who failed an initial FAA-acceptable color vision screening test and a subsequent practical color signal light test; and 117 third-class medical certificates with restrictions were issued to applicants who failed an initial FAA-acceptable color vision screening test and a subsequent practical color signal light test administered in the daytime, then passed a subsequent practical color signal light test administered at night.

[65] It was not possible to determine how many of the failed FAA-acceptable color vision screening tests were the FALANT test.

1.13.2.3 Postaccident Color Vision Deficiency Tests/Information

At the Safety Board's request, the first officer completed an extensive postaccident ophthalmic evaluation at the U.S. Air Force School of Aerospace Medicine (USAFSAM) at Brooks City-Base in Texas. In a letter to the Safety Board dated March 28, 2003, the Chiefs of the Visual Electrodiagnostic Laboratory and the Aerospace Ophthalmology Branch at Brooks described the nine color vision tests[66] conducted and their results. Subsequently, on September 30, 2003, the Board sent USAFSAM a letter containing follow-up questions. On November 5, 2003, the Board received a response from USAFSAM, which elaborated on the issues related to the first officer's color vision deficiency.[67] The March 28, 2003, letter stated, in part:

> During CV [color vision] testing, his oxygen saturation was recorded to be between 98-99% by pulse oxymeter....all test results were consistent with a congenital severe deuteranomaly.[[68]] This was based on the scores, symmetry, and consistency of his performance on a variety of red-green CV tests and ultimately was confirmed by two different anomaloscopes, performed by two independent examiners.
>
> [The first officer] did however "pass" the FALANT [test]. When developed, the FALANT was designed to pass about 30 [percent] of CV defectives (mild deficiencies), which were thought to be compatible with existing aviation tasks at the time. However, multiple studies of the FALANT indicate that it can misclassify even the most severe types of red-green CV deficiencies, and "pass" them....In [the first officer's] case, it also appears that the FALANT did not correctly identify his CV deficiency throughout his entire Navy flying career, nor when administered here at the ACS [Aeromedical Consultation Service]....Thus, we conclude that [the first officer] has a severe congenital deuteranomaly and that this defect was not identified properly by the FALANT. This testing inconsistency with the FALANT has been previously documented in the literature.
>
> When a variety of CV tests were evaluated by NATO-RTO[[69]] and published in RTO Technical Report 16, "Operational Colour Vision in the Modern Aviation Environment" in 2001, the following observations were made.

[66] Screening tests included tests commonly used for pilot certification and general color vision deficiency screening, including: PIP-I, PIP-II, PIP-III, FALANT, Farnsworth F2 plate, D-15, FM-100, Nagel anomaloscope and Spectrum Colour Vision Meter anomaloscope. The anomaloscope is a laboratory instrument used to classify color vision deficiencies with greater precision than can be obtained using the basic screening tests. For additional descriptions, see the March 28, 2003, letter in appendix C.

[67] The Safety Board's September 2003 follow-up letter and November 2003 response letter from USAFSAM are in appendix C.

[68] A deuteranomaly is a common color vision deficiency, present in about 5 percent of the male population, in which the pigments in the eye that typically respond to the middle range of color wavelengths have a sensitivity shifted to longer wavelengths, resulting in different interpretation of color stimuli from color normal individuals.

[69] NATO-RTO is the North Atlantic Treaty Organization—Research and Technology Organization.

> "Even though lantern tests have been used for close to one hundred years, their validation and the availability of information on their reliability is almost nonexistent. The evaluation of most lantern tests and the failure rates associated with normals and CV defectives are either conflicting or simply insufficient. Test validation for this class of tests is both complicated and perhaps confusing. Cross validation of one lantern against another is confounded because of the differences in intensity, wavelength, target size, and test distances.
>
> "Validation of lantern tests by use of an anomaloscope has very rarely been attempted and cross correlations with plate tests has produced ambiguous results. In most cases, therefore, plate tests precede lantern tests with the notable exception of the U.S. Navy where the Farnsworth lantern was used exclusively during this period of time."

The March 2003 letter from USAFSAM further stated the following:

> We believe that the type and degree of [the first officer's] congenital red-green defect could result in difficulties interpreting red-green and white signal lights that combine color and brightness, such as PAPIs and VASIs...it is possible in this case that the red lights of a PAPI could have been identified as 'yellow' at lower light levels or 'white' when the light was brighter.

The USAFSAM letter concluded that the first officer's "documented proficiency" suggested that he relied on "learned strategies" other than normal color vision to determine the airplane's position when using the PAPI/VASI during an approach.

In the November 2003 letter, the Chief of the USAFSAM Aerospace Ophthalmology Branch stated that the first officer's color vision discrimination was impaired to an extent that would "limit him to very nearly a gray-blue-yellow world…we believe that he would definitely have had problems discriminating the PAPIs as they were designed because the red lights would not appear to be red at all, but…some other wavelength that would make them more indistinguishable from white." The letter also stated that "it might be possible for someone with this type of [color vision] deficiency to use brightness differences between the white and red PAPI lights to help differentiate between them."

With respect to the FALANT screening test, the Chief of the USAFSAM Aerospace Ophthalmology Branch stated, "the FALANT was dropped as an official USAF air crew qualifying test in 1993.[[70]] It simply was not reliable and can misclassify [color vision] defectives. By design, it intentionally was supposed to only pass "mild" red-green [color vision] defectives, however, it can misclassify even moderate to severe [color vision] defectives and allow them to 'pass'."

[70] According to the November 2003 letter from USAFSAM, the current Air Force color vision screening includes a single red/green PIP test in the field; if this screening test is passed, pilot applicants may advance to Medical Flight Screening at Brooks Air Force Base, where they are subject to four additional color vision tests (the PIP-I, PIP-II, PIP-III, and the F2 plate tests).

The Safety Board notes that, in 1993, the University of Melbourne's Victorian College of Optometry conducted a study[71] to determine the ability of subjects with color vision deficiencies to correctly perceive the colors of simulated PAPI lights for use as an indicator of similar perceptions in pilot applicants. The study indicated that in up to 29 percent of the cases, subjects with color vision deficiencies similar to the first officer's mistakenly identified a red light signal as a white signal. According to the study, "this is a particularly dangerous error since confusing red with white may lead the pilot to reduce altitude when already too low." The study concluded that "colour vision defective subjects, with some exceptions, have difficulty distinguishing a simple two colour red-white code when the stimuli simulate the lights used in PAPI" and recommended that "consideration should be given to replacing the Farnsworth lantern by the more modern Holmes Wright Type A lantern which is used to administer the aviation colour vision standard in the [United Kingdom]." Additionally, the Board notes that other research[72] has shown that color vision deficiency can degrade the speed, as well as the accuracy, of color-related responses in operational settings. For example, a recent study found that subjects with red-green color vision deficiencies required about 30 percent more time to identify a red traffic signal than subjects with normal color vision. In addition, the study found that subjects with red-green color vision deficiencies misidentified a red signal as "yellow" more often than subjects with normal color vision.[73]

The Safety Board is aware of instances in which pilots who have met medical certification standards were involved in accidents related to deficient color vision. For example, a U.S. Navy aircraft mishap involved a pilot who passed the FALANT screen but was involved in the loss of an aircraft due to his failure to correctly interpret the color navigation lights of airplanes in the area (leading to the false perception of an impending collision).[74] In another case, a general aviation pilot with a medical waiver for red-green color vision deficiency was involved in an accident because he failed to recognize an orange-colored warning barrier indicating a closed runway.[75]

In addition, the Safety Board has observed color vision deficiency-related issues in other transportation modes, including a February 1996 railroad accident in which the

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[71] B.L. Cole and J.D. Maddocks, *A Simulation of PAPI Signals for Testing the Colour Vision of Applicants for a Pilot's License*, Final Report of an investigation undertaken for the Civil Aviation Authority. Victorian College of Optometry, University of Melbourne, Australia, November 1993.

[72] See H.W. Mertens and N.J. Milburn, "Performance of Color-Dependent Air Traffic Control Tasks as a Function of Color Vision Deficiency," *Aviation, Space, and Environmental Medicine* Vol. 67, No. 10 (1996): 919-927.

[73] See D.A. Atchison, C.A. Pedersen, S.J. Dain, and J.M. Wood, "Traffic Signal Color Recognition is a Problem for Both Protan and Deutan Dolor-Vision Deficients" *Human Factors* Vol. 45, No. 3 (2003): 495-503.

[74] A post-mishap ophthalmological evaluation indicated that the pilot was severely color deficient. See Department of the Navy, Office of the Judge Advocate General, "Investigation into the circumstances surrounding the loss of an F-4J aircraft, which occurred on 5 August 1980 aboard NAS Cubi Point, R.P."

[75] The description for this accident, CHI92LA259, can be found at the Safety Board's Web site at <http://www.ntsb.gov>. The report on this accident did not contain additional information regarding the pilot's color vision screening test that identified the pilot's deficiency, nor did it address the basis for the SODA/waiver.

Board determined that the train engineer failed "to perceive correctly a red signal aspect because of his diabetic eye disease and resulting color vision deficiency, which he failed to report…during annual medical examinations."[76] As a result of one of the Board's safety recommendations in this case (R-97-001, which was classified "Closed—Acceptable Action" on July 14, 2000), the color vision testing standards within the rail industry were revised to be consistent with the FAA color vision standards.

1.13.3 First Officer's Postaccident Hospitalization Information

Following the accident, the first officer was treated at a local (Tallahassee) hospital from July 26 to August 8, 2002. The hospital's records documented significant chest injuries, hypoxemia (decreased blood oxygenation), and right lower lobe lung consolidation throughout the hospitalization. The records also indicated that, when he was admitted to the hospital, the first officer's breathing rate was 16 bpm (while receiving 10 liters of 100 percent oxygen through a non-rebreather mask and before he received pain medications).

After the first officer was discharged from the hospital in Tallahassee on August 8, he traveled to his home in Maine, where he was subsequently hospitalized from August 10 to 23, 2002. This hospital's records documented an infection surrounding the first officer's right lung, a small tear in his left hemidiaphragm, and a large right pulmonary embolus and bilateral small pulmonary emboli, which were treated with anticoagulation medications.

The Safety Board consulted with the head of the Cardiopulmonary Division of the Duke University Medical Center Department of Radiology regarding the first officer's injuries and condition, based on documentation obtained from both hospitals. After reviewing the radiographs from the first officer's first postaccident hospitalization (in Tallahassee), the radiology consultant noted that although "[o]n one image [obtained July 31, 2002] the possibility of central filling defect in one of the right upper lobe vessels is raised…there is insufficient evidence to make a determination…that a pulmonary embolism is present or absent." After his subsequent review of the documentation from the first officer's second postaccident hospitalization (in Maine), the radiology consultant stated the following:

> Having reviewed a pulmonary embolism protocol CT [computed tomography] scan performed on [the first officer] on [August 16, 2002], I believe it is possible that a small filling defect seen in one of the right upper lobe pulmonary arteries on the previous CT scan of [July 31, 2002] may in fact have represented a small pulmonary embolus. This interpretation is made only in retrospect.

A pulmonary embolus is usually the result of a blood clot in a deep vein in the leg (known as deep vein thrombosis) that breaks off, travels to the lungs, and blocks one or

[76] See National Transportation Safety Board, *Near Head-on Collision and Derailment of Two New Jersey Commuter Trains Near Secaucus, New Jersey, February 9, 1996,* Railroad Accident Report NTSB/RAR-97/01 (Washington, DC: NTSB, 1997).

more of the arteries in the lungs. Studies indicate that, in most cases, pulmonary emboli result in no symptoms[77] and are detected during autopsies in more than half of the people who die during hospitalization.[78] Studies of patients with known pulmonary embolism indicate that more than 90 percent exhibit breathing rates greater than 16 bpm, about 88 percent report chest pain, about 84 percent report difficulty breathing,[79] and that hypoxemia is observed in about 75 percent.[80] According to these studies, the most common predisposing factor for deep vein thrombosis in patients with pulmonary embolism is immobilization resulting from fractured extremities or trauma to a lower extremity.

1.14 Fire/Explosion

A fuel-fed fire occurred after impact.

1.15 Survival Aspects

The accident was survivable; the three flight crewmembers received serious injuries. According to postaccident interviews, the captain, first officer, and flight engineer exited the airplane through the left-side sliding window in the cockpit.

1.16 Tests and Research

No technical tests or research were conducted.

1.17 Operational and Management Information

Federal Express Corporation was incorporated in June 1971 and began operations on April 17, 1973, operating 14 corporate-type jet airplanes from the airline's hub at MEM. After the deregulation of the air cargo industry in 1977, FedEx expanded and began using larger airplanes, including 727s and McDonnell-Douglas DC-10s, for its operations. In recent years, FedEx has added McDonnell-Douglas MD-11s and Airbus A-300s and

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[77] M.V. Huisman and others, "Unexpected High Prevalence of Silent Pulmonary Embolism in Patients With Deep Venous Thrombosis," *Chest* Vol. 95 No. 3 (Mar 1989): 498-502.

[78] M.T. Morrell and M.S. Dunnill, "The Post-Mortem Incidence of Pulmonary Embolism in a Hospital Population," *Br J Surg* Vol. 55 No. 5 (May 1968): 347-352.

[79] For additional information about breathing rate and chest pain in patients with pulmonary embolism, see W.R. Bell, T.L. Simon, and D.L. DeMets, "The Clinical Features of Submassive and Massive Pulmonary Emboli," *American Journal of Medicine* Vol. 62 No. 3 (Mar 1977): 355-360.

[80] P.D. Stein and others, "Clinical, Laboratory, Roentgenographic, and Electrocardiographic Findings in Patients Acute Pulmonary Embolism and No Pre-existing Cardiac or Pulmonary Disease," *Chest* Vol. 100, No. 3 (Sep 1991): 598-603.

A-310s to its fleet. At the time of the accident, FedEx employed 4,256 pilots and operated 128 Boeing 727s.

1.17.1 FedEx Flight Crew Training—General

According to FedEx's Flight Operations Training Manual (FOTM) and postaccident interviews with FedEx training personnel, the FAA had approved single-visit training for annual recurrent training of FedEx pilots. However, as a result of some incidents and the October 17, 1999, FedEx accident in Subic Bay, Philippines,[81] the company decided that semiannual training was more effective and elected to return to that schedule for its 727, DC-10, MD-11, and A-310 flight crews. The chief pilot stated that all 727 flight crewmembers received recurrent flight training at 6-month intervals, beginning 6 months after they qualified on a particular airplane. During every 12-month interval after qualification, a FedEx pilot would complete a proficiency training course in the simulator then, 6 months later, a recurrent ground training and a proficiency check in the simulator. According to the FedEx 727 Instructor Guide, annual CRM training was accomplished during the ground training before the proficiency check and would typically focus on one topic of interest (often related to recent aviation issues), such as night visual approaches, depth perception, black hole countermeasures, workload management, fatigue management, conflict management, "hurry-up" syndrome, decision-making in critical situations, flight deck distractions, and monitoring and challenging.

The Safety Board reviewed FedEx's training program/modules and other guidance the company provided its pilots in several potentially relevant subject areas, including: CFIT/black hole guidance, non-tower approaches, night visual approaches, stabilized approach criteria, and fatigue management.

1.17.1.1 FedEx CFIT Avoidance/Black Hole Guidance

FedEx's Flight Operations Manual (FOM) notes that the CFIT accident rate is 3 times greater at nighttime than during daylight hours and that, because many FedEx flights occur at night, a high percentage of FedEx flights would be at risk for a CFIT event. Therefore, FedEx developed a CFIT awareness training module, which it provided to its pilots during initial, upgrade, transition, and recurrent training sessions. This CFIT training identified flight crew factors involved in CFIT accidents, including poor decision-making, deviations from standard operating procedures, crewmember failure to challenge and monitor the performance of other crewmembers, lack of positional awareness, and flight-handling difficulties. FedEx flight crews were encouraged to identify CFIT risks before each approach, conduct thorough approach briefings, monitor each other's performance, and reduce any hesitation associated with go-around maneuvers.

[81] The description for this accident, DCA00RA002, can be found on the Safety Board's Web site at <http://www.ntsb.gov>.

FedEx also evaluated the airports used by its airplanes based on factors known to contribute to CFIT accidents (including airport and ATC capabilities, instrument approach availability, surrounding terrain, runway and approach lighting, ATC primary language spoken, and published departure procedures). Airports judged to be high or moderate CFIT risks were identified as such on salmon-colored approach pages, which were then distributed to FedEx flight crewmembers. In addition, FedEx printed the CFIT risk category of destination airports on all flight releases. TLH was identified as a moderate CFIT risk airport because ATC and radar coverage were not always available, it had no published departure procedures, and an ILS was not installed on all runways, which could potentially result in a nonprecision approach. FedEx's airport CFIT assessments were not runway specific.

FedEx also developed a recurrent training module on black hole approach hazards, which explained that visual approaches over water or dark, featureless terrain could be hazardous because of poor and misleading cues for evaluating the airplane's flightpath and height above the ground.[82] Additional risk factors cited in FedEx's training module included the airport's location (for example, on the edge of a small city; at a lower elevation than a nearby city; or near city lights on a hillside) and the brightness and type of runway lighting available. The training indicated that, without additional glideslope information, a black hole approach would typically result in a lower-than-usual, or concave, approach.

FedEx's black hole approach training module encouraged pilots to consider the potential for black hole illusions at specific airports, to use all available glideslope information, to perform a thorough approach briefing addressing potential black hole approaches, and to ensure adequate cross-check and monitoring. The training also encouraged pilots to monitor the airplane's glidepath using altitude and distance from the runway during nonprecision approaches and to monitor sink rate using the vertical speed indicator.

The captain and flight engineer had not received FedEx's CFIT avoidance/black hole training—in the captain's case, because he underwent upgrade training instead of recurrent training in the years this training was presented and, in the flight engineer's case, because the company had not offered that training module since he was hired in September 2001. The first officer had received FedEx's most recent CFIT avoidance/black hole training during recurrent training in 1999.

[82] According to chapter 8 of the FAA's Aeronautical Information Manual (AIM) (8-1-5), dated February 21, 2002, "an absence of ground features, as when landing over...darkened areas, and terrain made featureless...can create the illusion that the aircraft is at a higher altitude than it actually is. The pilot who does not recognize this illusion...overflying terrain which has few lights to provide height cues may make a lower than normal approach." In addition, the AIM states that upsloping runways at airports (for example, runway 9 at TLH) "can create the illusion that the aircraft is at a higher altitude than it actually is" with similar results. Research indicates that flying over featureless and unlit terrain can adversely affect a flight crew's ability to maintain adequate clearance from terrain. (Also see (a) C.L. Kraft and D.L. Elworth, "Night Visual Approaches," *Boeing Airliner Magazine* (Mar-Apr 1969) and (b) B. Schiff, "Black Hole Approach," *Boeing Airliner Magazine* (Jan-Mar 1994.)

1.17.1.2 FedEx Non-Tower Approach Guidance and Procedures

FedEx's Operations Specifications regarding the company's operations at airports without an operating control tower states the following:

> a) The certificate holder is authorized to conduct these operations, provided that the certificate holder determines that:
>
> 1) The airport is served by an authorized instrument approach procedure.
>
> 2) The airport has an approved source of weather [information].
>
> 3) The airport has a suitable means for the pilot-in-command to acquire timely air traffic advisories and the status of airport services and facilities.
>
> 4) The facilities and services necessary to safely conduct IFR operations are available and operational at the time of a particular operation.

FedEx's training curriculum, chapter 6, "Non-operational Control Tower Arrivals," states the following:

> Operations into airports during hours when the control tower is closed are not permitted unless the flight crew possesses briefing information describing non-tower operations for that airport.
>
> Briefing information may be supplied as:
>
> Jepp[esen chart] insert
>
> Photocopy of information placed in trip folder
>
> Information relayed from [Global Operations Control] with authority of duty officer
>
> The briefing information contains the following:
>
> The method for obtaining current weather from an approved source.
>
> The Common Traffic Advisory Frequency (CTAF).
>
> Ramp personnel are an additional source of advisories during tower off-hours.

The three accident flight crewmembers had received FedEx's non-tower approach training.

1.17.1.3 FedEx Visual Approach Guidance and Procedures

According to the FedEx training program, FedEx pilots receive visual approach training during the advanced simulation training portion of initial new-hire, initial equipment, transition, and upgrade flight training. The three accident flight crewmembers had received FedEx's visual approach training. FedEx's January 9, 2004, addendum to its submission states the following regarding nighttime visual approach training:

> Federal Express trains all its pilots in the simulator on night visual approaches without the use of glideslope information. Crewmembers are expected to demonstrate they can utilize the proper 'sight picture' to discern and fly a safe visual approach at night. The first officer had successfully completed this training.

The guidance contained in FedEx's FOTM indicates that visual approaches would be accomplished during the simulator training periods. A review of the FedEx 727 Instructor Guide revealed the following:

- The importance of getting the correct sight picture for landing cannot be over-emphasized.
- Visual landings...maneuvers and procedures to be accomplished during the...simulator session.
- A briefing item concerning non-tower arrival and departure operations...in the...simulator session.
- A briefing containing information regarding visual approaches and visual descent points is given to pilots in transition/upgrade training.

FedEx's FOM indicates that during a straight-in visual approach, flight crews should "plan to be established on the extended centerline of the runway in use NO LATER than 4 [nautical miles] from the runway threshold." Further, on page 7-1-7-2, the FOM states that the airplane should be established on final approach at a position and altitude such that it can be stabilized, with 30° flaps and on target airspeed, by the time it reaches 500 feet agl. The FOM states that at 500 feet agl, the "pilot not flying"[83] must determine whether the airplane is stable (in which case, the crew continues the approach) or unstable (in which case, the crew should go-around). The FOM identifies the following common errors in a visual approach: poor airspeed control, poor altitude control, failure to stabilize the aircraft on a proper glidepath, late configuration (for example, excessive airspeed and altitude too close to the runway), and failure to correct to a proper glidepath.

[83] According to FedEx's lead instructor for CRM training, the CRM training department wanted to change the term "pilot not flying" to "pilot monitoring," with corresponding changes in the company's philosophy and training because the new term and focus would increase flight crew awareness of actively cross-checking functions/actions within the cockpit. The FAA has addressed this issue in its revised AC 120-71A, and, according to FedEx's submission on this accident, some airlines have already incorporated the "pilot monitoring" concept.

The FedEx 727 Company Flight Manual (CFM), chapter 7, states the following regarding a stabilized final approach: "a typical stabilized final approach for a 3 degree glideslope, in no wind conditions, will be approximately 1 degree pitch, 700 [foot per minute rate of descent], V_{app} (approach airspeed), and 3,000–3,500 pph of fuel flow."[84] According to FedEx check airmen, for the accident airplane and engines under conditions similar to those encountered during the accident approach, this fuel flow would likely correspond to EPR values between 1.30 and 1.45 (this estimate was supported by data supplied by representatives from P&W, the JT8D-15/15A engine manufacturer.) Chapter 7 of the FedEx 727 CFM also lists the callout and monitoring duties for the flying and non-flying pilots during a visual approach. According to this list, the non-flying pilot is to make a call—"stable" or "unstable go-around"—when the airplane descends through 500 feet. The non-flying pilot is also to advise the flying pilot of any deviations in airspeed (more than 5 knots off target airspeed below 1,000 feet), sink rate (no more than 1,000 fpm below 1,000 feet), and glideslope and localizer (if available) during the visual approach. Both flying and non-flying pilots are to announce visual cues as appropriate during a visual approach.

1.17.1.4 FedEx Stabilized Approach Criteria and Procedures

According to Chapter 6 of FedEx's FOM that was effective at the time of the accident, the stabilized approach corridor begins at 500 feet agl for airplanes that are cleared for a visual approach and at 1,000 feet agl for airplanes that are cleared for an instrument approach. The stabilized approach is defined as follows:

- The aircraft must have landing gear down and locked; the flaps/slats must be in the final landing configuration.
- The engines must be spooled-up[[85]] and steady at the proper approach setting.
- The proper descent angle and rate of descent must be established and maintained. All available landing aids (ILS, VASI, PAPI, etc.) must be used. Non-precision approaches may require a slightly steeper angle until reaching the MDA (minimum descent altitude).
- Airspeed must be stable and within the range of target speed (+/- 5 knots of target). Momentary and minor deviations are only tolerated if immediate corrections are made.

The FOM emphasized that "the procedures and parameters listed above are not merely targets, THEY ARE MANDATORY CONDITIONS AND LIMITS. ANY DEVIATION OCCURRING AT OR BEYOND THE BEGINNING OF THE STABILIZED APPROACH CORRIDOR REQUIRES A MANDATORY GO-AROUND." According to FedEx policy, "the decision to execute a go-around is both

[84] The fuel flows identified in the FedEx 727 CFM applied to the 727-100 airplane. The FedEx Instructor Guide states that the fuel flows should be increased by 500 pph for the 727-200 airplane; all other parameters/conditions for a stabilized approach are the same.

[85] The term "spooled up" would reflect the previously discussed engine power settings typical for a fully configured 727 on a stabilized approach—fuel flows of 3,000 to 3,500 pph, which would correspond to about 1.3 to 1.45 EPR.

prudent and encouraged anytime the outcome of an approach or landing becomes uncertain." Further, chapter 6 of the FOM states the following, in part:

> The decision a pilot must make before descending below the minimum altitude for the approach is not a commitment to land.
>
> The operational decision to continue an approach using visual means must be based on information the pilot accumulates throughout the approach. Since many variables are involved, the final decision to commit to a landing is the captain's and is primarily a judgment based on all relevant factors.

When queried about FedEx's criteria for a stabilized approach, the captain of flight 1478 told investigators, "If cleared for instrument approach—it has to be 'spooled up,' fully configured, on glidepath, at 1,000 feet [msl]. For a visual approach—'spooled up,' fully configured, on glidepath at 500 feet [msl]." He further stated that he believed the accident airplane performance was consistent with the criteria for a stabilized visual approach.

1.17.1.5 FedEx's Fatigue Management Training and Other Fatigue-Related Information

In response to several Safety Board recommendations, on September 8, 1995, the FAA revised AC 120-51D, Appendix 3, to encourage operators to provide pilots with "factual information about the detrimental effects of fatigue and strategies for avoiding and countering its effects" as part of an airline pilot training program,[86] although such training is not required by current regulations. Research indicates that during a time period from about midnight to 0600, and especially between 0300 and 0500, there is a higher probability of flight crew errors and accidents because a pilot's alertness and performance are degraded by fatigue.[87] Another common effect observed in fatigue-related accidents is a tendency to continue an approach despite increased cues indicating a need to discontinue the approach.[88]

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[86] The inclusion of fatigue as a recommended training topic (within a CRM training curriculum) was made in response to Safety Board recommendations that the FAA require U.S. air carriers to provide fatigue countermeasure information to air crews in initial and recurrent training (Safety Recommendations A-94-5 and A-94-73 were classified "Closed—Acceptable Action" on January 16, 1996).

[87] See T. Akerstedt, "Review Article: Shift Work and Disturbed Sleep/Wakefulness," *Sleep Medicine Reviews* Vol. 2, No. 2 (1998): 117-128.

[88] See (a) National Transportation Safety Board, *Runway Overrun During Landing, American Airlines Flight 1420, McDonnell Douglas MD-82, N215AA, Little Rock, Arkansas, June 1, 1999,* Aircraft Accident Report NTSB/AAR-01/02 (Washington, DC: NTSB, 2001). (b) National Transportation Safety Board, *Controlled Flight Into Terrain, Korean Air Flight 801, Boeing 747-300, HL7468, Nimitz Hill, Guam, August 6, 1997*, Aircraft Accident Report NTSB/AAR-00/01 (Washington, DC: NTSB, 2000). (c) National Transportation Safety Board, *Uncontrolled Collision With Terrain, American International Airways Flight 808, Douglas DC-8-61, N814CK, U.S. Naval Air Station, Guantanamo Bay, Cuba, August 18, 1993*, Aircraft Accident Report NTSB/AAR-94/04 (Washington, DC: NTSB, 1994). Additionally, the Board discussed fatigue in a 1994 safety study. See National Transportation Safety Board, *A Review of Flightcrew-Involved, Major Accidents of U.S. Air Carriers, 1978 Through 1990,* Safety Study NTSB/SS-94/01 (Washington, DC: NTSB, 1994).

In 1990, FedEx's CRM instructors developed and implemented a 2-hour course on sleep and fatigue management,[89] which was provided to all company pilots as recurrent training. The training addressed causes of fatigue, circadian rhythms, sleep loss, and the physical, social, emotional, and safety-related consequences of fatigue. This 2-hour course was also added to FedEx's indoctrination course for all new hires. In addition, in 2000, FedEx CRM instructors distributed a fatigue management card to all FedEx pilots to be inserted in their Jeppesen approach binders.

Additional company policies supporting the fatigue management training included the availability of sleep/nap rooms in operational areas and a policy allowing pilots to remove themselves from the flight schedule due to fatigue.[90] According to a company representative, feedback from pilots about the fatigue training was very positive; the only criticism received was that some pilots wished the training occurred closer to when they actually started flying when it would have had greater operational relevance. In addition, discussions were held within the training department about reintroducing fatigue management as a recurrent topic for line pilots who were not exposed recently to this training.

FedEx's fatigue management training addressed suggested strategies for minimizing and managing fatigue in the home environment and during trips, including taking steps to prevent sleep interruptions, ensuring adequate rest before a trip, making sleep a priority during layovers, sleeping two or more times a day, developing a regular pre-sleep routine, using relaxation techniques, creating a good sleep environment, and maintaining healthy exercise and diet habits. The training also suggested the following strategies for in-flight management of fatigue: interact with other crewmembers, stretch, turn on cockpit lights, maintain a proper cockpit temperature, use caffeine, and/or take a nap (in coordination with other crewmembers). FedEx also encouraged its pilots to keep a sleep journal, study their circadian rhythms, and determine what strategies work best for them.

Further, in its fatigue management training and in its formal company policy, FedEx encouraged pilots to "call in fatigued" if they were unable to get adequate rest. The agreement between FedEx and the FedEx pilots' union stated the following regarding this policy:

> A pilot who is unable to operate his trip or a portion thereof due to fatigue shall notify [crew scheduling] immediately and shall be placed in sick leave status. A

[89] According to FedEx training instructors, the fatigue segment was developed based on National Aeronautics and Space Administration (NASA) models, such as the NASA Ames Fatigue Management Training Module developed by NASA under FAA funding as a result of personal contacts and company participation in a NASA fatigue study.

[90] This program is consistent with research literature advocating a comprehensive approach to fatigue management in operational settings, although this program did not incorporate all potential elements of such a comprehensive approach. For example, literature advocates developing technology in areas such as scheduling algorithms and monitoring the effectiveness of interventions. See M.R. Rosekind, P.H. Gander, K.B. Gregory, R.M. Smith, D.L. Miller, R. Oyng, L.L. Webbon, and J.M. Johnson, "Managing Fatigue in Operational Settings 2: An Integrated Approach," *Behavioral Medicine* Vol. 21 (1996): 166-170.

> fatigued pilot shall be compensated, and his sick leave account(s) shall be debited, for the...missed trip or portion thereof. The pilot shall automatically return from sick leave status at the scheduled conclusion of his trip unless the pilot notifies the Company...to continue his sick leave status. A pilot who is fatigued shall be considered to have an illness or injury. Nothing in this paragraph shall minimize a pilot's responsibility to ensure that he has adequate rest prior to reporting for duty.

During postaccident interviews, the first officer and flight engineer confirmed that they received fatigue management training at FedEx and described some of the strategies learned. The captain did not recall receiving formal fatigue management training but indicated that he had received "flyers" on the subject. The first officer stated, "I've flown very tired. I've never flown where I felt it was unsafe." None of the three accident flight crewmembers had turned down a trip because of fatigue.

1.17.2 Postaccident FedEx Actions

After this accident, FedEx incorporated several changes in its systems. For example, the company separated its quality assurance function from its training function and initiated a "standards check" on a new captain's first flight after IOE. Additionally, to ensure that pilots do not select runways for expediency rather than safety, FedEx revised its FOM to provide specific direction regarding the type of approach and landing aids to be used by pilots when the destination airport's tower is closed. The company's stabilized approach criteria now requires pilots to ensure that the airplane is stabilized at 1,000 feet agl for both visual and instrument approaches to allow them more time to accomplish checklists and focus on the landing.

FedEx also revised its practices to require that only airplanes equipped with operating enhanced GPWS (EGPWS) and traffic collision avoidance systems (TCAS) be dispatched to non-tower and high-CFIT-risk airports. Further, the company stated that it planned to have EGPWS and TCAS installed in all its airplanes by late 2004. The EGPWS provides an aural ground proximity warning based on global positioning system data rather than radio-altitude information used by the GPWS. However, the Safety Board's evaluation of the EGPWS software available at the time of the accident indicated that it would not have resulted in a warning in this case because the airplane's flightpath did not penetrate the warning envelope.[91] As a result of this accident, the EGPWS manufacturer is developing an upgrade (expected to be approved in 2004) that would have provided the pilots involved in this accident with an aural warning about 19 seconds before the first sounds of impact were recorded by the CVR.

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[91] The manufacturer's subsequent review supported the Safety Board's evaluation.

1.18 Additional Information

1.18.1 Hypoxia-Related Information

Paragraph 8-1-2a of the FAA's AIM defines hypoxia as "a state of oxygen deficiency in the body sufficient to impair functions of the brain and other organs." The AIM states that "Although a deterioration in…vision occurs at a cabin altitude as low as 5,000 feet, other significant effects of hypoxia [impaired judgment, memory, alertness, etc.] do not occur in the normal healthy pilot below 12,000 feet."

Research[92] also indicates that hypoxia can adversely affect color vision and that individuals with defective color vision can have substantially reduced color discrimination ability at mild levels of hypoxia (as might be expected in pilots operating at typical cabin altitudes). According to the Chief of the USAFSAM Aerospace Ophthalmology Branch, hypoxia could further degrade any residual red-green (white) hue discrimination ability that a severely deuteronomalous pilot might have, and lower levels of illumination would further degrade such a pilot's ability to discern colors.

1.18.2 DOT Operator Fatigue Management Program

The FAA recently participated (with other transportation modal administrations) in a Department of Transportation (DOT) Human Factors Coordinating Committee, which led the DOT's Operator Fatigue Management Program effort to develop practical tools for use by individuals and industries to better maintain vigilance and alertness on the job. One such tool is a fatigue management reference guide.[93] The reference guide was intended to provide basic information to operators in all transportation modes on how to develop an effective fatigue management program using available scientific evidence and best industry practices. For example, the reference guide notes that one of the important components of a fatigue management training program is its ongoing evaluation and refinement. Further, the guide suggests that conducting pilot surveys and monitoring objective safety data to refine existing programs are among the best procedures for such evaluation and refinement. In addition, the DOT program is developing additional

[92] See (a) J.T. Ernest and A.E. Krill, "The Effect of Hypoxia on Visual Function. Psychophysical Studies," *Invest Ophthalmol.* Vol. 10, No. 5 (May 1971): 323-8. (b) A.J. Vingrys and L.F. Garner, "The Effect of a Moderate Level of Hypoxia on Human Color Vision," *Doc Ophthalmol* Vol. 66, No. 2 (Jun 1987): 171-85. (c) C. Bouquet and others, "Color Discrimination Under Chronic Hypoxic Conditions (Simulated Climb "Everest-Comex 97")," *Percept Mot Skills.* Vol. 90, No. 1 (Feb 2000): 169-79.

[93] U.S. Department of Transportation, (In draft-2003). Commercial Transportation Operator, Fatigue Management Reference. Washington, DC: DOT Research and Special Programs Administration. This work follows, in part, from previous Safety Board recommendations that the DOT develop and disseminate educational material for transportation industry personnel and management regarding shift work; work and rest schedule; and proper regimens of health, diet, and rest (Safety Recommendation I-89-2, which was classified "Closed—Acceptable Action" on May 25, 2001).

products for industry use (which are expected to become available in late 2004), including:

- A Fatigue Management Reference Guide: a compendium of current science and practical information on approaches to fatigue management and countermeasure usage;
- A Fatigue Model Validation Procedure: a practical and methodologically sound approach for validating output from fatigue modeling software being tailored for transportation application;
- Work Schedule Representation and Analysis Software: a software tool to aid managers and schedulers in evaluating and designing ergonomic work schedules to promote on-duty alertness;
- Program Evaluation Framework: a cross-modal fatigue management research logic model that provides a blueprint for evaluating current knowledge, information needs, and points of leverage between DOT agencies; and
- Business Case Development Tool Suite: a documented methodology and supporting analytical tools to aid company safety managers in building a case for senior management support of fatigue management activities.

Recent interviews with DOT personnel working on the fatigue management training program indicate that future efforts should involve setting up a multimodal pilot program to test the tools they are developing. DOT personnel indicated that the Federal Railroad Administration is beginning validation tests on some of these tools in operational settings within the railroad industry.

1.18.3 Crew Familiarity/Attention/Monitoring Information

In a 1994 safety study of crew-related air carrier accidents,[94] the Safety Board found that 84 percent of the reviewed accidents involved inadequate crew monitoring or challenging. Similarly, research conducted to support the Flight Safety Foundation's Approach and Landing Accident Reduction (ALAR) efforts revealed that poor monitoring and cross-checking were involved in 63 percent of the reviewed approach and landing accidents.[95] A 1998 National Aeronautics and Space Administration (NASA) research project of cockpit interruptions and distractions reviewed 107 Aviation Safety Reporting System reports to identify tasks that crews typically neglected at critical moments while attending to other tasks.[96] It found that 69 percent of the neglected tasks involved either

[94] NTSB/SS-94/01, 40-41.

[95] R. Khatwa and R.L. Helmreich, "Analysis of Critical Factors During Approach and Landing Accidents and Normal Flight," *Killers in Aviation: FSF Task Force Presents Facts About Approach-and-Landing and Controlled-Flight-into-Terrain Accidents. Flight Safety Digest.* (November—December 1998, January—February 1999).

[96] K. Dismukes, G. Young, and R. Sumwalt, "Cockpit Interruptions and Distractions: Effective Management Requires a Careful Balancing Act," *ASRS Directline* (December 1998).

failure to monitor the status or position of the airplane or failure to monitor the actions of the pilot flying or taxiing.

The Safety Board notes that recent FAA guidance and industry actions emphasize the importance of careful crew monitoring. For example, in February 2003, the FAA revised AC 120-71A, "Standard Operating Procedures," to describe the philosophy of and benefits to be derived from a "pilot monitoring" program. AC 120-71A notes that "operators should review existing standard operating procedures...and modify those that can detract from monitoring. AC 120-71A also indicates that several air carrier operators have changed the title of "pilot not flying" to "pilot monitoring" because it is more appropriately descriptive. According to the March 17, 2003, FedEx submission on this accident, the company currently uses the pilot monitoring concept for certain approaches and at least one other air carrier has completely incorporated the pilot monitoring concept into its system.

Additionally, in January 2004, the FAA revised AC 120-51E, "Crew Resource Management Training," to emphasize the critical role of the monitoring pilot. This AC states that the monitoring function is particularly essential during approach and landing when CFIT accidents are most common. The AC suggested that operators redistribute some of the workload items typically accomplished during the approach and landing phase to less demanding phases of flight when possible. According to the AC, this would allow crewmembers to focus more on monitoring airplane and crewmember performance during a critical phase of flight. FedEx's lead CRM instructor suggested that changing the term "pilot not flying" to "pilot monitoring" would result in increased pilot awareness of the importance of the monitoring function. (Since this accident, FedEx has also developed a new human factors course that focuses on captain leadership and pilot monitoring skills.)

Research indicates that a lack of crew familiarity can contribute to a flight crew's failure to fly and monitor a stabilized approach. For example, in a study of major aviation accidents involving human performance issues, in which a large number of monitoring errors were observed, the Safety Board found that 73 percent of the accidents occurred on the first day that the captain and first officer had flown together; 44 percent occurred on the first flight leg.[97] Simulator research supports this, showing that flight crews with recent operating experience together communicate more frequently overall and perform better at solving in-flight emergencies than those that did not (even when the latter crews had completed a long rest period not available to crews with recent operating experience).[98]

[97] These percentages are substantially higher than would be expected by chance and draw attention to the importance of crew familiarity at preventing serious monitoring and other human performance errors.

[98] H.C. Foushee, J.K. Lauber, M.M. Baetge, and D.B. Acomb, *Crew Factors in Flight Operations: III. The Operational Significance of Exposure to Short-Haul Air Transport Operations*. National Aeronautics and Space Administration, NASA Technical Memorandum 88322, August 1986.

Additionally, research shows that conscious attention can be highly selective and that people may not respond to important objects that may be plainly visible.[99] For example, a simulator study found that pilots could become so engrossed in performing a landing using a heads-up display that some pilots failed to see that another airplane was blocking the runway.[100] Similarly, accident data confirm that an air crew can respond to a visual illusion of airport distance and fail to use accurate PAPI information that is directly visible.[101] Fatigue and high workload are both likely to increase selective attention and the likelihood of missing relevant information.

1.18.4 Previously Issued Safety Recommendations

1.18.4.1 CFIT-Related Safety Recommendation

As a result of the August 1997 CFIT accident at Nimitz Hill, Guam,[102] the Safety Board issued Safety Recommendation A-00-10, which recommended that the FAA do the following:

> Conduct or sponsor research to determine the most effective use of the monitored approach method and the maximum degree to which it can be safely used and then require air carriers to modify their procedures accordingly.

Pending the results of the FAA's research on use of the monitored approach method, on January 31, 2002, Safety Recommendation A-00-10 was classified, "Open—Acceptable Response."

1.18.4.2 Fatigue-Related Safety Recommendations

Since 1989, the Safety Board has issued more than 70 safety recommendations related to fatigue for all modes of transportation. In addition, human fatigue in transport operations has been included in the Board's annual list of Most Wanted Transportation Safety Improvements since the list's inception in September 1990.

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[99] (a) A. Mack, "Inattentional Blindness," *Current Directions in Psychological Science* Vol. 12, No. 5 (2003): 180-184. (b) F.W. Hawkins, *Human Factors in Flight* (Aldershot, England: Ashgate Publishing Limited, 1997) 116.

[100] R.F. Haines, "A Breakdown in Simultaneous Information Processing. In G. Obrecht & L.W. Stark (Eds.)," *Presbyopia Research* (New York: Plenum Press, 1991) 171-175.

[101] See Transportation Safety Board of Canada (1996). Tail Strike on Landing, Canadian Airlines International, Boeing 767-375 C-FOCA, Halifax, Nova Scotia, 08 March 1996, Report A96A0035.

[102] See National Transportation Safety Board, *Controlled Flight Into Terrain, Korean Air Flight 801, Boeing 747-300, HL7468, Nimitz Hill, Guam, August 6, 1997,* Aircraft Accident Report NTSB/AAR-00/01 (Washington, DC: NTSB, 2000).

In Safety Recommendation A-99-45, the Safety Board urged the FAA to:

> Establish within 2 years scientifically based hours-of-service regulations that set limits on hours of service, provide predictable work and rest schedules, and consider circadian rhythms and human sleep and rest requirements.[[103]]

The FAA issued Notice of Proposed Rulemaking (NPRM) 95-18, "Flight Crewmember Duty Period Limitations, Flight Time Limitations and Rest Requirements," in December 1995, published a notice of intent in the *Federal Register* to indicate the agency's intent to enforce regulations concerning flight time limitations and rest requirements in June 1999, and indicated its intent to issue a supplemental NPRM in spring 2001 (no supplemental NPRM has been issued to date). However, in April 2001, the Safety Board indicated that it was frustrated by the FAA's lack of progress concerning this safety issue and classified Safety Recommendation A-99-45 "Open—Unacceptable Response." In October 2001, the Board reiterated Safety Recommendation A-99-45 in its final report on the American Airlines flight 1420 accident at Little Rock, Arkansas.[104]

[103] See National Transportation Safety Board, *Evaluation of U.S. Department of Transportation Efforts in the 1990s to Address Operator Fatigue,* Safety Report NTSB/SR-99/01 (Washington, DC: NTSB, 2000).

[104] National Transportation Safety Board, *Runway Overrun During Landing, American Airlines Flight 1420, McDonnell Douglas MD-82, N215AA, Little Rock, Arkansas, June 1, 1999,* Aircraft Accident Report NTSB/AAR-01/02 (Washington, DC: NTSB, 2001).

2. Analysis

2.1 General

The captain, first officer, and flight engineer possessed valid airman and medical certificates.

The captain, first officer, and flight engineer had received the training and off-duty time prescribed by Federal regulations and company requirements.

The accident airplane was properly certificated and maintained and was equipped and dispatched in accordance with applicable regulations and industry practices. There was no evidence of any preexisting powerplant, system, or structural failure. Cargo loading for the accident flight was routine; no cargo loading anomalies were observed, and the airplane was operating within prescribed center of gravity limits. Hazardous materials on board the airplane were not a factor in the accident. The accident airplane and its cargo were not factors in the accident.

At the time of the accident, the winds were calm and visibility was unrestricted, with a forecast of a few clouds at or below 100 feet. The pilots reported that no significant meteorological conditions were present that adversely affected their visual approach to runway 9 at TLH; ground observers' statements corroborated the pilots' reports. Additionally, the Safety Board's review of ATC information revealed no evidence of any ATC problems or issues related to the accident. Weather and ATC were not factors in the accident.

Postaccident examination of the airport lighting for runway 9, including the PAPI lighting system (the only glidepath information available for runway 9) indicated that the airport lighting was capable of normal operation and had been activated by the pilots almost 3 minutes before the airplane began to impact the trees. During postaccident interviews, all three pilots reported observing red and white lights on the PAPI display, consistent with normal PAPI operation. Although the flight engineer and captain reported seeing a pink PAPI signal on one of the four PAPI lights at some time during the approach, they also reported seeing red and/or white lights (which would have provided appropriate glidepath guidance) at the same time.[105] Investigators who examined the PAPI boxes during the on-scene investigation (including the NATCA representative and other members of the investigative team) noted no particle contamination or condensation on the PAPI lights, and the investigation developed no evidence to support the possibility of such contamination. The airport lighting systems, including the PAPI lights, were not a factor in the accident.

[105] A pilot might observe a pink PAPI signal as a result of condensation on the PAPI lenses or briefly when the airplane is transiting the narrow zone between the red and white PAPI signals.

This analysis will focus on the flight crewmembers' decisions and performance—as a crew and individually—to consider why none of the three flight crewmembers recognized that the airplane was below the glidepath during about the last 40 seconds of the approach and responded accordingly.

2.2 The Accident Approach

Postaccident interviews with the pilots and examination of the CVR and FDR data indicated that the en route portion of the accident flight from MEM to TLH was routine and that the pilots engaged in normal duties and discussions as the airplane neared TLH. CVR evidence indicated that although the flight crew originally planned to land on runway 27, when they were about 10 minutes from touchdown, they decided to land on runway 9 instead.

According to the Safety Board's airplane performance study, when the airplane became established on the final approach course about 2 1/2 miles from the approach end of runway 9, the PAPI lights would have shown a low indication (one white and three red lights). Almost immediately thereafter, the PAPI lights would have shown a very low indication (four red lights), which would have been viewable from the cockpit for the remainder of the flight.

As the airplane descended through 500 feet agl at 1,248 fpm, 152 knots, and with engines operating at about 1.17 EPR, the captain announced that the approach was "stable." The Safety Board notes that, although the airplane's airspeed was within the target range, the airplane did not meet FedEx's criteria for a stabilized approach because its rate of descent was greater than FedEx's recommended 1,000 fpm,[106] the engines' power settings were less than the expected 1.3 to 1.45 EPR, and its glidepath was low as indicated by the PAPI light guidance. According to FedEx procedures at the time of the accident, if a visual approach was not stabilized when the airplane descended through 500 feet agl, the pilots were to perform a go-around. The Safety Board concludes that the accident approach was not stabilized as the airplane descended through 500 feet agl and that the pilots should have detected this and performed a go-around.

As the pilots continued the approach, the flight engineer read the before landing checklist query items, with the captain responding, in accordance with FedEx procedures. About 0536:49, the CVR recorded the first officer commenting that he was going to have to stay a little higher or he was "gonna lose the end of the runway." The airplane's subsequent descent rate gradually decreased to about 960 fpm; however, the airplane remained significantly below the proper glidepath. FDR data showed that, shortly thereafter, the engine power began to increase further, reaching about 1.34 EPR about 0537:12. During this time, the captain stated that the runway was starting to "disappear…a little" but then said, "think we'll be alright."

[106] As previously noted, the captain's and first officer's VSIs were not instantaneous—that is, the instruments displayed data that lagged behind the airplane's actual rate of descent, which was derived from the FDR data. However, the manufacturer's simulations indicated that the pilots' VSIs would have displayed a rate of descent of at least 1,000 fpm when the airplane descended through 500 feet agl.

In postaccident statements, the flight crew and ground observers indicated that there were no obstructions to visibility along the approach path. However, the comments made by the first officer ("gonna lose the end of the runway") and captain ("disappear…a little") suggest that they may have encountered a temporary obstruction to visibility (for example, clouds or mist) as they approached runway 9. If such an obstruction existed, it may also have obscured the PAPI lights. Although a temporary obstruction might help explain the flight crew's failure to recognize the PAPI guidance while that obstruction was present, it does not explain why the three pilots failed to recognize the presence of four red PAPI lights throughout the rest of the approach. Further, according to FedEx procedures (and FAA regulations), if the approach end of the runway became obscured at any time during the visual approach, the pilots should have performed a go-around.

The night visual approach to runway 9 at TLH was conducted over a protected national forest area that was devoid of ground lights or other visible references by which the pilots could judge their height above terrain. FedEx's recurrent training module on black hole approaches, which the first officer received in 1999,[107] warned that pilots conducting visual approaches at night over terrain with minimal visible ground features or lighting often perceive the airplane to be higher than its actual altitude. Research has shown that in situations like this, a pilot typically flies a lower-than-normal approach until the error starts to become apparent (usually about 2 to 3 miles from the runway), at which point the pilot takes corrective action. Indeed, on the night of the accident, the first officer did fly a concave approach, with a steeper-than-normal initial descent, which is characteristic of a black hole approach. However, in the case of the accident flight, the first officer did not modify the steepness of the approach path in time, and the airplane collided with trees and terrain.

The Safety Board concludes that the approach to runway 9 at TLH (which was flown over unlighted terrain and in night visual conditions) resulted in black hole conditions, which likely contributed to the flight crew's failure to properly perform the approach. However, the Safety Board also concludes that PAPI lights, such as those installed at runway 9 at TLH, are a recognized countermeasure for use in black hole conditions and should have been, but were not, effectively used to maintain an appropriate glidepath by the first officer (who was the flying pilot) or by the captain and flight engineer (who, under the principles of basic crew coordination, were in a position to receive this information and initiate a corrective response).[108]

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107 FedEx records indicate that the captain and flight engineer had not received this training. In the captain's case, he missed the black hole recurrent training module because he attended upgrade training instead. The flight engineer had not been with the company long enough to attend recurrent training.

108 The Safety Board also considered the possibility that the 0.4 percent upslope on the first third of runway 9 contributed to the flight crew's low approach. The geometric appearance of upsloping runways can create the illusion that an airplane's approach path is higher than desired, and a pilot might compensate by flying a lower-than-normal approach. However, in this case, the upslope was minor and only present for the first third of runway 9, and the remainder of the runway was a gradual downslope. Therefore, it is unlikely that the illusion created by the runway's slight upslope contributed significantly to the pilots' failure to maintain the correct glidepath.

2.3 Fatigue

Research[109] on human alertness has shown that the early morning hours are often associated with degraded alertness and performance; the accident occurred about 0537 local time (0437 in the flight crew's domicile time zone). However, because FedEx conducted most of its 727 domestic operations overnight, operating at these hours was likely a normal occurrence for the flight crew. Therefore, the Safety Board evaluated each flight crewmember's performance during the accident flight and their specific activities and sleeping history in the days before the accident for evidence of routine,[110] and especially nonroutine, factors conducive to the development of fatigue.

2.3.1 Role of Fatigue—Captain

The Safety Board's examination of the captain's sleep history revealed evidence of a sleep deficit. The captain was off duty from about midnight on July 24 until the accident flight. However, he described his sleep during the two nights preceding the accident trip as "not really good" or "marginal" because his sleep was interrupted to take care of the family dog. The captain stated that after he learned that he was assigned to the accident trip, he got about 3 1/2 hours of "pretty good" sleep.

The CVR recording revealed that the captain made several small errors during the accident flight that suggest he may not have been fully alert. These errors included incorrect readback of the radio frequency, incorrect repetition of weather information, incorrectly addressing Jacksonville Center as Atlanta Center (twice), and repeatedly clicking the microphone button five and six times to activate the airport lighting (rather than the seven times requested by the first officer).[111] These errors were not consistent with other pilots' statements regarding the captain's performance on previous flights, which described his competence, use of standard FedEx procedures and callouts, good judgment, upbeat nature, and good CRM skills. Further, there was no evidence of previous deficient performance in the captain's training or operational history.

Further, the captain's decision-making and monitoring during the approach were not characteristic of his past performance. For example, although CVR evidence indicated that the captain initially planned to land on runway 27 because it had an ILS and was more convenient to the FedEx ramp, he agreed to land on runway 9 to accommodate the first officer's suggestion. When the first officer subsequently began to reconsider his runway selection, the captain said, "yeah, it dudn't matter." The captain's apparent indifference about the landing runway and the ultimate decision to change to a runway that did not

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109 See T. Akerstedt, "Review Article: Shift Work and Disturbed Sleep/Wakefulness," *Sleep Medicine Reviews* Vol. 2, No. 2 (1998): 117-128.

110 The Safety Board notes that information regarding the flight crewmembers' activities and sleeping history in the days before the accident was obtained from postaccident pilot and witness statements.

111 Keying the microphone five or six times would result in medium intensity runway lights rather than high intensity runway lights but would not have affected the PAPI brightness/intensity. It is unlikely that this adversely affected the flight crew's performance of the approach.

have a source of precision vertical guidance and provided little advantage over the originally selected runway suggests that the captain's decision-making may have been degraded. Additionally, although CVR evidence revealed instances in which the captain appeared to be monitoring the first officer's performance, the captain declared the approach "stable" when the airplane descended through 500 feet, despite the airplane's excessive descent rate and reduced engine power settings. Most significantly, the captain failed to observe and respond to the four red PAPI lights that were displayed throughout most of the final approach. Any one of these items should have prompted the captain to call for a go-around.

Many of the small errors made by the captain and his deficient performance during the approach to TLH were consistent with fatigue. Research and previous accident investigation experience indicate that fatigue can cause pilots to fixate on one aspect of a situation and not respond effectively to warnings from other aspects, such as a stickshaker, GPWS, or visual warnings. Further, one of the common deficiencies observed in fatigue-related accidents is a tendency to continue an approach despite indications that the approach should be discontinued. This fatigue-related performance inertia is evidenced by decision-making and monitoring deficiencies. The Safety Board notes that during the accident approach, there was not much evidence of substantive evaluation or discussion of the consequences of the decision to change the landing runway to runway 9. For an experienced captain to support a decision to change landing runways (when it substantially increased cockpit workload late in the approach and removed a potentially critical source of glideslope guidance) suggests degraded decision-making consistent with the effects of fatigue.[112]

Therefore, on the basis of the early hour of the accident, the captain's sleep history, and his performance deficiencies recorded by the CVR, the Safety Board concludes that the captain was likely impaired by fatigue and this impairment contributed to his degraded performance (especially in the areas of crew coordination and monitoring) during the approach to TLH.

2.3.2 Role of Fatigue—First Officer

The Safety Board's review of crew interviews and the first officer's sleep history revealed that he reported having difficulty adjusting his sleep cycle to the reserve-duty schedule. The first officer told investigators that this was the first reserve schedule he had flown in several years and that it was difficult on his body because the sleep-wake cycle was frequently changing between day and night sleeping schedules. He stated that he normally preferred to bid schedules that allowed either all-day or all-night sleep periods over 1-week blocks.

[112] For a similar example of inappropriate landing runway choice caused by fatigue, see National Transportation Safety Board, *Uncontrolled Collision With Terrain, American International Airways Flight 808, Douglas DC-8-61, N814CK, U.S. Naval Air Station, Guantanamo Bay, Cuba, August 18, 1993*, Aircraft Accident Report NTSB/AAR-94/04 (Washington, DC: NTSB, 1994).

On July 23, the first officer flew an early morning trip that began about 0330 and ended about 1100. Upon completion of this trip, he slept several hours during the day and slept again that night. The first officer was off-duty the next day (July 24). He stated that he awoke about 0930 to 1030 and went to sleep about 2100, sleeping for a few hours in preparation for a trip that was scheduled to begin about 0230 on July 25. When he completed the trip about 0830, the first officer got several hours of sleep during the day in the layover hotel. He characterized the quality of sleep as "no better or worse than most day sleeps." On the evening of July 25, he returned to duty, flew several legs, and arrived at MEM about 2300 expecting to return home. Instead, he learned that he was assigned to fly the accident trip in a few hours. The first officer contacted a duty officer to confirm that the trip assignment did not result in his exceeding flight and duty time limits and agreed to fly the trip.[113] The first officer got about 1 1/2 hours of "good" sleep in a company sleep room before starting the accident trip. When asked whether he felt alert, he stated, "I don't recall feeling alert." A friend and roommate stated that the first officer "appeared tired" as he waited for the crew bus to take him to MEM for the accident trip. The accident captain stated that he had an impression that the first officer "might be a little tired" and stated that the first officer discussed the rest difficulties of his reserve schedule.

During the accident flight, the first officer's performance was deficient in ways that appear inconsistent with characterizations of his past performance, including his failure to request 30° of flaps until he was prompted to do so by the captain, his failure to "stay a little higher" on the approach (as he noted would be necessary to avoid losing the runway), his failure to maintain appropriate engine EPR settings during the approach, and his failure to respond to PAPI guidance that indicated the airplane was extremely low on the approach. Further, the first officer did not recognize these deficiencies and decide to perform a go-around. The Safety Board notes that there were times during the accident flight that the first officer's performance was more consistent with characterizations of his past performance; for example, he provided a comprehensive briefing for the initially planned approach to runway 27, and he recognized his failure to correctly identify the airport.

Although the first officer's errors and occasionally deficient performance are consistent with the effects of fatigue, in the case of the failure to maintain an appropriate glidepath, the investigation revealed a potential alternate explanation. Specifically, there was evidence that the first officer's ability to use PAPI information was limited by a congenital color vision deficiency (see section 2.4.1).[114] Therefore, the Safety Board concludes that the first officer's schedule and his reported difficulty adapting to frequently changing sleep cycles were conducive to the development of fatigue impairment that contributed to his degraded performance during the approach to TLH; however, there were also other factors affecting the first officer's performance (for example, his color vision deficiency).

[113] Although he agreed to take the accident trip, the first officer told investigators that he planned to file a grievance regarding the assignment.

[114] In addition, his color vision deficiency may have been exacerbated by hypoxia (see section 2.4.2).

2.3.3 Role of Fatigue—Flight Engineer

In the case of the flight engineer, there was little evidence of factors conducive to the development of fatigue in the days before the accident. He was off-duty on July 22 and 23 and reported resting at home with normal overnight sleeping and afternoon naps. On July 24, he reported on-duty at 2200 for a deadhead trip to MEM then departed MEM at 0230 on July 25, arriving at the layover destination about 0830. The flight engineer, who said that he began taking naps as a result of the company fatigue management training class, indicated that he got some rest on the deadhead flight and in a recliner chair at MEM before this trip and that he got "pretty solid" sleep in the layover hotel from 0900 to 1530. He returned to MEM the evening of July 25 and rested in a recliner chair with his eyes closed for 30 minutes to 1 hour before the accident trip. The flight engineer indicated that he felt "pretty rested" for the accident flight. During postaccident interviews, the captain stated that the flight engineer seemed to be alert during the accident flight.

During the accident flight, the flight engineer provided the captain and first officer with pertinent weather and airport information and pertinent prompts (such as suggesting performance of the approach and before landing checklists). However, he failed to correct the captain's inaccurate repetition of the weather information. More seriously, he failed to effectively monitor the airplane's status during the final moments of descent as required by company procedures. This failure was inconsistent with other pilots' descriptions of the flight engineer's performance and his reputation with the company.[115] However, it is possible that the flight engineer's poor monitoring of the late stages of the approach was the result of his workload during the somewhat rushed approach,[116] the presumption that the two forward-facing flight crewmembers were adequately monitoring the approach, or some combination of factors.

Although the early hour at which the accident occurred suggests the presence of fatigue for all the crewmembers, the investigation indicated that the flight engineer received normal rest until 1 day before the accident trip, supplemented his nightly sleep with good quality sleep and rest at other times before the trip, and appeared to make an adequate adjustment to an overnight flying schedule in preparation for the accident flight. Further, there was no evidence of deficient performance that could be specifically related to fatigue during the accident flight. On the basis of this evidence, the Safety Board concludes that it is possible that the flight engineer was impaired by fatigue at the time of the accident; however, it is also possible that the flight engineer's poor monitoring of the late stages of the approach was the result of his workload during the somewhat rushed approach, the presumption that the two forward-facing flight crewmembers were adequately monitoring the approach, or some combination of factors.

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[115] FedEx was evaluating the flight engineer for a check airman position.

[116] Although the flight engineer told investigators that he did not feel rushed during the approach, the completion of the checklist just 7 seconds before the CVR recorded the first sounds of impact resulted in less time to focus his attention forward to monitor the final approach.

2.3.4 Fatigue Management Training

The flight engineer said that as a result of the company fatigue management training class, he began taking naps to augment his nightly sleep. Both he and the first officer rested in the company sleep/nap areas before the accident trip. FedEx records indicated that the captain received fatigue management training during recurrent training in 1991, but he stated that he did not recall the training. Although the company's policies allowed for it, the three accident crewmembers indicated that they had never turned down a trip due to fatigue.

The Safety Board notes that the FAA recently participated (with other transportation modal administrations) in a DOT Operator Fatigue Management Program effort to develop a fatigue management reference guide. The reference guide was intended to provide basic information to operators in all transportation modes on how to develop an effective fatigue management program using available scientific evidence and best industry practices. In addition, the DOT program is developing additional products for industry use (expected to become available in late 2004), such as software to aid in designing work schedules that promote alertness. Such products can provide useful guidelines and tools for companies that are willing to go beyond current regulations by developing and implementing a fatigue management program (like FedEx).

Fatigue in transportation operations has been on the Safety Board's list of most wanted safety recommendations since the list's initiation in September 1990. In May 1999, the Board issued a safety report that concluded that, despite acknowledgement that fatigue is a significant factor in transportation accidents, little progress has been made to revise the hours-of-service regulations to incorporate the results of the latest research on fatigue and sleep issues. Thus, the Board issued Safety Recommendation A 99-45 in its report, asking the FAA to "establish within 2 years scientifically based hours-of-service regulations that set limits on hours of service, provide predictable work and rest schedules, and consider circadian rhythms and human sleep and rest requirements." However, the FAA's response to this recommendation has not been acceptable, and, in April 2001, Safety Recommendation A-99-45 was classified, "Open—Unacceptable Response." The Safety Board concludes that the circumstances of this accident, in part, demonstrate the continuing need for fatigue management efforts similar to those being developed by the DOT Operator Fatigue Management Program in the aviation industry.

2.4 Physiological Issues That May Have Affected the First Officer's Performance

2.4.1 The First Officer's Color Vision Deficiency

At the Safety Board's request, the first officer completed an extensive postaccident ophthalmic evaluation at USAFSAM, which was intended to determine the extent of the color vision defect noted on his medical certificate and its possible significance during the

approach to TLH. During this evaluation, the first officer passed the FALANT color vision screen but failed seven additional red/green color vision tests. The USAFSAM specialists' report stated that the first officer had a severe congenital deuteranomaly that could result in "difficulties interpreting red-green and white signal lights." The report also stated the following:

> We believe that he would definitely have had problems discriminating the PAPIs...because the red lights would appear not to be red at all, but...more indistinguishable from white than red....it would be extremely unlikely that he would be capable of seeing even the color pink on the PAPI...more likely a combination of whites and yellows and perhaps, not even that difference.

The USAFSAM conclusions are supported by the results of an Australian study, which showed that individuals with color vision deficiencies similar to the first officer's mistakenly identified the red light signal as white in up to 29 percent of the cases. The Safety Board notes that this error could be especially dangerous when interpreting a PAPI signal because it might lead a pilot to descend lower when the airplane is already too low. The Australian study recommended that "consideration should be given to replacing the Farnsworth lantern" as a color vision certification test for pilots.

The specialists at USAFSAM reported that most individuals with color vision deficiencies develop an ability to "differentiate" between normal colors based on cues other than hue or wavelength, such as differences in shade or brightness. The length of the first officer's military and civilian aviation career suggests that, in general, he had been able to compensate for his deficient color vision. However, during the approach to runway 9 at TLH, the first officer had to rely more heavily on his color vision because the PAPI lights were the only reliable source of glidepath information in the black hole approach environment leading to runway 9. The first officer's interpretation of the PAPI lights would have been even more challenging because all four lights were red during most of the final approach. As a result, there would have been no differing levels of brightness for the first officer to perceive across the lights (as might have been apparent if both white and red PAPI lights were visible), nor would there have been a change in brightness to observe (as there might have been when a PAPI light transitioned from white to red during the descent). Either of these would likely have assisted the first officer's color interpretation.

It is possible that the first officer interpreted the uniform PAPI light indications as "white" because that was consistent with available visual indications (for example, the black hole illusion and the slight runway upgrade) that would lead him to perceive that the airplane was higher on the approach than it was. Such an interpretation would be consistent with the first officer's conduct of earlier portions of the approach, with occasionally excessive rates of descent and lower-than-normal engine power settings. However, just after the airplane descended through 500 feet agl, the first officer stated, "(I'm) gonna have to stay just a little bit higher, (or) I'm gonna lose the end of the runway." About this time, the FDR data indicated that the airplane's descent rate began to decrease from about 1,400 to 900, then to 500 fpm. It was not clear exactly why the first officer moderated the descent rate at this time; however, it is possible that he was trying to

reconcile a conflict between the 500-foot GPWS callout and a mistaken illusion of the airplane's elevation above the field. The Safety Board considers it unlikely that the first officer made this moderate reduction in the airplane's descent rate because he recognized the PAPI indication of four red lights; recognition of four red PAPI lights at such a late stage in the approach should have resulted in a more aggressive response (such as an immediate climb or a go-around).

As previously discussed, the Safety Board is aware of other instances in which pilots with valid medical certificates were involved in accidents related to deficient color vision, including a U.S. Navy pilot who had passed the FALANT screen and a general aviation pilot operating with a waiver for color vision deficiency. In addition, the Safety Board has observed color vision deficiency-related issues in other transportation modes.

It is apparent that in some situations, accurate color vision may be critical to a degree that is not currently reflected in the application of the aviation medical certification standards,[117] specifically in those situations in which color discrimination capabilities are critical to the safe execution of the task and there are no redundant cues to aid the discrimination. Based on the available evidence, the Safety Board concludes that the first officer suffered from a severe color vision deficiency that made it difficult for him to correctly identify the color of the PAPI signal during the below-glidepath, nighttime, visual approach to runway 9 at TLH.[118]

The Safety Board notes that current aviation medical certification standards for color vision and related screening tests do not emphasize the full complexity of color in modern operational situations, which include not only navigation lights, PAPI/VASI displays and light gun signals, but may also involve color cockpit displays, including weather radar, other flight instruments and gauges, and annunciator panels. Another possible shortcoming of current color vision certification standards and related screening tests is that they may not appropriately evaluate a pilot's ability to rapidly discriminate among colors. Therefore, the Safety Board concludes that existing aviation medical certification standards for color vision and use of related screening tests may not ensure detection of color vision deficiencies that can be detrimental to safety; it is possible that in some emergency situations, the speed of color recognition may assume an importance that is not currently reflected in the standards.

The Safety Board further notes that some color vision screening tests currently in use in the aviation industry are inadequate to confirm that a pilot has the "ability to perceive those colors necessary for the safe performance of airman duties" as required by the certification standards. For example, the FALANT screening test, which is an approved color vision screening method for aeromedical certification, failed to identify

[117] FAA medical standards for color vision require that pilots at all levels of certification possess the "ability to perceive those colors necessary for the safe performance of airman duties."

[118] Another instance during the accident flight may provide an additional example of the first officer's deficient color vision adversely affecting his ability to perform his duties. His initial mistaken identification of a flashing white light as the rotating beacon at TLH reflected his failure to discern the color properties (green and white) of an airport rotating beacon.

the first officer's severe color vision deficiency. In addition, according to the November 5, 2003, USAFSAM letter, other color vision tests (including the PIP) have failed to detect color vision deficiencies in pilot applicants. The letter indicated that the USAF now uses a battery of tests that it believes identifies all color vision deficiencies in applicants.

FAA records indicate that there is a substantial pilot population who, like the first officer, have color vision deficiencies but successfully completed the FALANT or other color vision deficiency screening test. For example, during postaccident testing, the first officer successfully completed the FAA's light gun signal test,[119] and as a result, the first officer was issued a first-class medical with no restrictions, limitations, or SODAs. The high success rate of the light gun signal test among individuals who have previously failed another FAA-acceptable color vision screening test (about 95 percent) suggests that this test may not identify all the individuals with severe color deficiencies that could affect their ability to safely operate an aircraft. (The issuance of a color-vision-related SODA to the first officer on the basis of operational experience appears to fall outside current and past available written FAA guidelines regarding appropriate aeromedical disposition of an airman who fails a color vision test.) Further, it is likely that, in some circumstances, these color vision deficiencies may also result in unsafe conditions.

Therefore, the Safety Board concludes that one or more of the color vision screening tests currently approved for use in the aviation industry (for example, the FALANT) are not adequate and that these tests should be identified and their use discontinued. The Safety Board believes that the FAA should conduct research to determine the effectiveness of each of the current FAA-approved color vision test protocols (including the color signal light test) at effectively screening out pilot applicants with color vision deficiencies that could impair their ability to perform color-related critical aviation tasks, including (but not limited to) correct interpretation of glideslope information and in-cockpit displays that use color to convey information. The research should take into account the time typically available to perform each task, particularly under emergency conditions, and the potential effect of mild hypoxia (as might occur at typical cabin altitudes) on color vision deficiencies. Further, the Safety Board believes that the FAA should, based on the results of the research requested in the previous recommendation, develop a standard battery of tests to be performed at least once on each applicant for a Class 1 or 2 medical certificate that would prevent applicants with color vision deficiencies that could impair their ability to perform color-related critical aviation tasks from being certificated without limitations.

2.4.2 The First Officer's Breathing Rate

The Safety Board examined the breathing sounds that were recorded by the first officer's channel of the CVR to determine whether they reflected the presence of an acute medical condition, specifically a pulmonary embolus and resultant hypoxia. This issue is

[119] Although operational use of light gun signals in the current aviation environment is very limited, the light gun signal test is still used by the FAA to establish a color-deficient individual's ability to use color operationally.

significant because research[120] indicates that any mild hypoxia could further degrade a pilot's color vision (especially in pilots with existing color vision deficiencies) and affect his decision-making abilities. An elevated breathing rate, as evident on the CVR, is one symptom consistent with the diagnosis of this condition (although research shows that people suffering from pulmonary embolus are often asymptomatic); there was also some CVR evidence of breathing patterns consistent with those observed during hypoxia. CT scans taken within 5 days after the accident revealed possible indications of pulmonary embolus, the presence of which was later confirmed. Further, the first officer's reported knee injury in the weeks before the accident and his subsequent efforts to minimize movement of the injured limb could have been an initiating event for the development of deep vein thrombosis, a precursor to a pulmonary embolism.

The rapid breathing rate recorded by the CVR during the last 20 minutes of the accident flight is not sufficient evidence, when considered by itself, of pulmonary embolus and resultant hypoxia. The first officer reported that he experienced no signs of distress, pain, or difficulty breathing (potential symptoms of a pulmonary embolus) before the accident. Further, there was no diagnosis of a pulmonary embolus or other physiological abnormality immediately after the accident. Because there was no definitive evidence to support the presence of a pulmonary embolus at the time of the accident, it was not possible to determine whether the first officer was suffering from a pulmonary embolus and resultant hypoxia at the time of the accident. The Safety Board was not able to determine the cause of the elevated breathing rates recorded on the first officer's CVR channel.

2.5 Crew Coordination/Monitoring Information

Contrary to FedEx standard operating procedures and training, the flight crew did not work together effectively to fly and monitor a stabilized approach into TLH. There was no evidence to suggest that the deficient crew coordination was a characteristic pattern of performance for these three crewmembers (a review of company records and interviews with other pilots generated positive and complimentary descriptions about their abilities). Yet, the captain and flight engineer failed to recognize the solid red PAPI display (although there was no evidence that either had deficient color vision) and take action to correct the low approach. This failure might partially be the result of their accomplishment of tasks that required their attention inside the cockpit, such as those involved in completing the landing checklist. However, it would be normal and expected for both the captain and flight engineer to monitor the runway environment at other times during the final landing sequence, and it is difficult to understand why no one reacted to the visually salient PAPI information.

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[120] See (a) J.T. Ernest and A.E. Krill, "The Effect of Hypoxia on Visual Function. Psychophysical Studies," *Invest Ophthalmol* Vol. 10, No. 5 (May 1971): 323-8. (b) A.J. Vingrys and L.F. Garner, "The Effect of a Moderate Level of Hypoxia on Human Color Vision," *Doc Ophthalmol* Vol. 66, No. 2 (Jun 1987): 171-85. (c) C. Bouquet and others, "Color Discrimination Under Chronic Hypoxic Conditions (Simulated Climb "Everest-Comex 97")," *Percept Mot Skills* Vol. 90, No. 1 (Feb 2000): 169-79.

Research shows that attention can be highly selective and that people may not respond to important objects that may be plainly visible.[121] For example, a simulator study found that some pilots became so engrossed in performing a landing using a heads-up display that they failed to see an airplane blocking the end of the runway. Similarly, accident data confirm that an air crew can respond to a visual illusion of airport distance and fail to use accurate PAPI information that is directly visible. Fatigue and high workload are both likely to increase the possibility of missing relevant information. If the captain and flight engineer monitored the runway environment during the final approach and if the PAPI signal was visible without obstruction, inappropriate selective attention could help explain the failure of both crewmembers to respond to the PAPI information.

The actions of the captain and first officer added to the complexity of the final approach and the need for careful monitoring by the flight engineer. For example, the captain decided, at the first officer's suggestion, to change the landing runway, resulting in the performance of a nonprecision approach instead of a precision approach. The first officer was slow to correctly identify the airport, and the airplane was rather close to the airport before it was aligned on final approach.

Thus, during the somewhat hurried final approach that ensued, the flight engineer might have served as a significant defense against an accident by carefully monitoring and crosschecking. The Safety Board notes that to accomplish the last item on the before landing checklist (landing lights), the flight engineer would need to look forward to check the landing light switches. According to FedEx procedures, the flight engineer should have remained facing forward, monitoring the approach for the remainder of the flight (in this case, 7 seconds). The flight engineer's failure to adequately monitor the approach, either because of his workload, reliance on other crewmembers, inattention, or some combination of factors, removed the last defense against the accident.

Further, research indicates that a lack of crew familiarity may have contributed to the flight crew's failure to fly and monitor a stabilized approach.[122] For example, in a study of major aviation accidents involving human performance issues, in which a large number of monitoring errors were observed, the Safety Board found that 73 percent of the accidents occurred on the first day that the captain and first officer had flown together; 44 percent occurred on the first flight leg. Simulator research supports this, showing that

[121] See (a) A. Mack, "Inattentional Blindness," *Current Directions in Psychological Science* Vol. 12, No. 5 (2003): 180-184. (b) F.W. Hawkins, *Human Factors in Flight* (Aldershot, England: Ashgate Publishing Limited, 1997) 116. (c) R.F. Haines, "A Breakdown in Simultaneous Information Processing. In G. Obrecht & L.W. Stark (Eds.)," *Presbyopia Research* (New York: Plenum Press, 1991) 171-175.

[122] See (a) National Transportation Safety Board, *A Review of Flightcrew-involved, Major Accidents of U.S. Air Carriers, 1978 Through 1990*, Safety Study NTSB/SS-94/01 (Washington, DC: NTSB, 1994). (b) R. Khatwa and R.L. Helmreich, "Analysis of Critical Factors During Approach and Landing Accidents and Normal Flight," *Killers in Aviation: FSF Task Force Presents Facts About Approach-and-Landing and Controlled-Flight-into-Terrain Accidents. Flight Safety Digest.* (November—December 1998, January—February 1999). (c) K. Dismukes, G. Young, and R. Sumwalt, "Cockpit Interruptions and Distractions: Effective Management Requires a Careful Balancing Act," *ASRS Directline* (December 1998). (d) H.C. Foushee, J.K. Lauber, M.M. Baetge, and D.B. Acomb, *Crew Factors in Flight Operations: III. The Operational Significance of Exposure to Short-Haul Air Transport Operations*. National Aeronautics and Space Administration, NASA Technical Memorandum 88322, August 1986.

flight crews with recent operating experience together communicate more frequently overall and perform better at solving in-flight emergencies than those that did not (even though, in some cases, crews without recent operating experience together were returning to flight duty after a rest period, which was not the case with crews with recent operating experience together). Therefore, the FedEx accident crew may have had a disadvantage because they were engaged in their first leg as a crew[123] and had not yet developed the level of personal working relationship that facilitates effective coordination. Although compliance with FedEx's standard operating procedures should have helped eliminate flight crew coordination errors, the lack of flight crew familiarity may help explain why such crew coordination and monitoring was deficient during the accident sequence.

During postaccident interviews, FedEx's lead instructor for CRM told investigators that the CRM department had been lobbying the airline to change the term "pilot not flying" to "pilot monitoring" because they wanted non-flying pilots to think more about the importance of their monitoring role. The circumstances of this accident demonstrate the importance of flight crewmembers actively monitoring the performance of other crewmembers, as well as their own performance. According to the ALAR study conducted by the Flight Safety Foundation, inadequate monitoring by flight crewmember(s) was a factor in 63 percent of approach and landing accidents.

The Safety Board notes that in February 2003, the FAA revised AC 120-71A, "Standard Operating Procedures," to describe the philosophy of and benefits to be derived from a "pilot monitoring" program. AC 120-71A also indicates that several air carrier operators have changed the title of "pilot not flying" to "pilot monitoring" because it is more appropriately descriptive. According to the March 17, 2003, FedEx submission on this accident, the company now uses pilot monitoring for certain approaches, and at least one other air carrier has completely incorporated the pilot monitoring concept into its system. The Safety Board concludes that the circumstances of this accident support the recent increase in emphasis on crew monitoring reflected in recent initiatives by the FAA and aviation industry.

[123] The captain and flight engineer had been paired once before but neither had a clear recall of the experience.

3. Conclusions

3.1 Findings

1. The captain, first officer, and flight engineer possessed valid airman and medical certificates.

2. The captain, first officer, and flight engineer had received the training and off-duty time prescribed by Federal regulations and company requirements.

3. The accident airplane and its cargo were not factors in the accident.

4. Weather and air traffic control were not factors in the accident.

5. The airport lighting systems, including the precision approach path indicator lights, were not a factor in the accident.

6. The accident approach was not stabilized as the airplane descended through 500 feet above ground level, and the pilots should have detected this and performed a go-around.

7. The approach to runway 9 at Tallahassee Regional Airport (which was flown over unlighted terrain and in night visual conditions) resulted in black hole conditions, which likely contributed to the flight crew's failure to properly perform the approach.

8. Precision approach path indicator lights, such as those installed at runway 9 at Tallahassee Regional Airport, are a recognized countermeasure for use in black hole conditions and should have been, but were not, effectively used to maintain an appropriate glidepath by the first officer (who was the flying pilot) or by the captain and flight engineer (who, under the principles of basic crew coordination, were in a position to receive this information and initiate a corrective response).

9. The captain was likely impaired by fatigue and this impairment contributed to his degraded performance (especially in the areas of crew coordination and monitoring) during the approach to Tallahassee Regional Airport.

10. The first officer's reported difficulty adapting to his schedule and frequently changing sleep cycles were conducive to the development of fatigue impairment that contributed to his degraded performance during the approach to Tallahassee Regional Airport; however, there were also other factors affecting the first officer's performance (for example, his color vision deficiency).

11. It is possible that the flight engineer was impaired by fatigue at the time of the accident; however, it is also possible that the flight engineer's poor monitoring of the late stages of the approach was the result of his workload during the somewhat rushed approach, the presumption that the two forward-facing flight crewmembers were adequately monitoring the approach, or some combination of factors.

12. The circumstances of this accident, in part, demonstrate the continuing need for fatigue management efforts similar to those being developed by the Department of Transportation Operator Fatigue Management Program in the aviation industry.

13. The first officer suffered from a severe color vision deficiency that made it difficult for him to correctly identify the color of the precision approach path indicator signal during the below-glidepath, nighttime, visual approach to runway 9 at Tallahassee Regional Airport.

14. Existing aviation medical certification standards for color vision and use of related screening tests may not ensure detection of color vision deficiencies that can be detrimental to safety; it is possible that in some emergency situations, the speed of color recognition may assume an importance that is not currently reflected in the standards.

15. One or more of the color vision screening tests currently approved for use in the aviation industry (for example, the Farnsworth Lantern screening test) are not adequate; these tests should be identified and their use discontinued.

16. The circumstances of this accident support the recent increase in emphasis on crew monitoring reflected in recent initiatives by the Federal Aviation Administration and aviation industry.

3.2 Probable Cause

The National Transportation Safety Board determines that the probable cause of the accident was the captain's and first officer's failure to establish and maintain a proper glidepath during the night visual approach to landing. Contributing to the accident was a combination of the captain's and first officer's fatigue, the captain's and first officer's failure to adhere to company flight procedures, the captain's and flight engineer's failure to monitor the approach, and the first officer's color vision deficiency.

4. Recommendations

As a result of the investigation of the FedEx flight 1478 accident, the National Transportation Safety Board makes the following recommendations to the Federal Aviation Administration:

> Conduct research to determine the effectiveness of each of the current Federal Aviation Administration-approved color vision test protocols (including the color signal light test) at effectively screening out pilot applicants with color vision deficiencies that could impair their ability to perform color-related critical aviation tasks including (but not limited to) correct interpretation of glideslope information and in-cockpit displays that use color to convey information. The research should take into account the time typically available to perform each task, particularly under emergency conditions, and the potential effect of mild hypoxia (as might occur at typical cabin altitudes) on color vision deficiencies. (A-04-46)

> Based on the results of the research requested in Safety Recommendation A-04-46, develop a standard battery of tests to be performed at least once on each applicant for a Class 1 or 2 medical certificate that would prevent applicants with color vision deficiencies that could impair their ability to perform color-related critical aviation tasks from being certificated without limitations. (A-04-47)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

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Member

Adopted: June 8, 2004

5. Appendixes

Appendix A
Investigation

The National Transportation Safety Board was initially notified of this accident on the morning of July 26, 2002. A full go-team was assembled in Washington, D.C., and traveled to the accident scene. The go-team was accompanied by representatives from the Safety Board's Offices of Government and Public Affairs and Transportation Disaster Assistance. No Board Member traveled to the accident site.

The following investigative groups were formed during the course of this investigation: Structures, Systems, Powerplants, Air Traffic Control, Meteorology, Operations, Human Performance, Medical Factors, Airport/Survival Factors, Airplane Performance, Flight Data Recorder, Cockpit Voice Recorder (CVR), and Hazardous Materials. In addition, a CVR Sound Study was conducted.

Parties to the investigation were the Federal Aviation Administration, the Boeing Commercial Airplane Group, Federal Express, Air Line Pilots Association, National Air Traffic Controllers Association, Pratt & Whitney, and the Tallahassee Regional Airport.

Appendix B
Cockpit Voice Recorder Transcript

The following is a transcript of the Fairchild model A100 CVR installed on the accident airplane. Only radio transmissions to and from the accident airplane were transcribed. The CVR transcript reflects the 32 minutes and 12 seconds before power was lost to the CVR. All times are eastern standard time, based on a 24-hour clock.

LEGEND

RDO	Radio transmission from accident aircraft, FedEx 1478
CAM	Cockpit area microphone voice or sound source
HOT	Hot microphone voice or sound source[1]
	For RDO, CAM, and HOT comments: **-1** Voice identified as the Captain **-2** Voice identified as the First Officer **-3** Voice identified as a Second Officer **-?** Unidentified voice or sound
GPWS	Synthesized voice from the Ground Proximity Warning System (GPWS) as heard through the Cockpit Area Microphone channel.
SZW	Radio transmission identified as the Seminole VORTAC identifier.
GVR	Radio transmission from the Gainesville Flight Service Station.
ATIS	Radio transmission from the Tallahassee Automated Terminal Information System.
RAMP	Radio transmission from the Federal Express ramp station at TLH.
CTR	Radio transmission from the Atlanta Air Route Traffic Control Center.
CTR2	Radio transmission from the Jacksonville Air Route Traffic Control Center.
UNK	unknown voice or sound source.

[1] This recording contained audio from three hot microphones. The voices or sounds heard on these channels may also be captured by the CAM channel. Normally, the source acronym used in the transcript refers to the 'best' source or the source that captured the sound most clearly.

*	Unintelligible word
@	Non-pertinent word
#	Expletive
- - -	Break in continuity or interruption in comment
( )	Questionable text
[ ]	Editorial insertion
...	Pause

Note 1: Times are expressed in Eastern Daylight Time (EDT).

Note 2: Generally, only radio transmissions to and from the accident aircraft were transcribed.

Note 3: Words shown with excess vowels, letters, or drawn out syllables are a phonetic representation of the words as spoken.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
[Start of Transcript]			
0505:13.9 CAM	[Start of Recording]		
0505:25 HOT-1	[Sound of humming/singing]		
0506:08 HOT-1	right now we are about two hundred miles out uhh David.		
		0506:33 SZW	[sound similar to Morse code identifier for SZW VOR - heard on Captain's channel]
0506:38 HOT-1	(like) Seminole on number one.		
0507:09 HOT-?	[sound of humming - heard on both Captain's and First Officer's channel]		
0507:11 HOT-1	[sound similar to yawn]		
		0509:48.0 RDO-3	Gainesville radio, FedEx fourteen seventy eight.
		0510:14.9 RDO-3	Gainesville radio, FedEx fourteen seventy eight.
		0510:26 GVR	FedEx fourteen seventy eight, Gainesville radio.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
		0510:29.5 RDO-3	Gainesville good morning, FedEx fourteen seventy eight, I was wonder'n if you had the weather for Tallahassee, sir?
		0510:35 GVR	current Tallahassee reporting one hundred scattered, one eight thousand scattered, two five thousand scattered, visibility niner, wind one two zero at five, temperature and dewpoint are two two, over.
		0510:50.5 RDO-3	fourteen seventy eight copies, one hundred scattered, and several other layers, winds one two zero at five, visibility nine, temperature and dewpoint two two, do you have an altimeter setting?
		0511:00 GVR	three zero one zero.
		0511:02.9 RDO-3	three zero one zero, 'preciate it. have a good day.
		0511:06 GVR	good day sir.
		0512:08 ATIS	* five five point four. Tallahassee tower will resume normal operations at six hundred local time.
0512:23 HOT-3	The weather is uh, winds are one two zero at five, visibility nine, uh one hundred scattered, and several other layers, temperature and dewpoint are both two two, altimeter three zero one zero.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0512:35 HOT-1	all right... sounds good.		
0512:39 HOT-3	uh, what runway you think you gonna try for?		
0512:41 HOT-1	two seven.		
0512:42 HOT-3	two seven?		
0512:43 HOT-1	yeah.		
0512:46 HOT-1	and what'd you say the winds were again, one sixty-		
0512:48 HOT-3	one-		
0512:48 HOT-1	-at nine?		
0512:49 HOT-3	-one two zero at five.		
0512:50 HOT-1	two oh, yeah, two seven, yeah *.		
		0513:13 CTR	FedEx fourteen seventy eight, descend at pilot's discretion maintain flight level two four zero.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
		0513:17.8 RDO-1	discretion to two four zero, FedEx fourteen seventy eight.
0513:21 HOT-2	twenty four.		
0513:22 HOT-1	roger.		
0513:30 HOT-2	got lots of moon over here.		
0513:32 HOT-1	* lotsa what?		
0513:34 HOT-2	lots of moon over here.		
0513:35 HOT-1	yeah, I'ze gonna say, it's pretty thin that's what I was lookin' at, I don't think *.		
		0513:54.9 RDO-3	Tallahassee ramp, FedEx fourteen seventy eight.
		0514:02 RAMP	* seventy eight.
		0514:04.7 RDO-3	Tallahassee good morning, FedEx fourteen seventy eight, approximately twenty five, thirty minutes out aircraft is up, lookin' for a parkin' spot and the power.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
		0514:12 UNK	[sound similar to background radio noise on First Officer's channel for approx 26 seconds]
		0514:13 RAMP	* twenty five out * gate number two * you'll be comin in on taxiway charlie * pick up the marshaller * facing south *.
0514:24 HOT-1	* # ice *.		
		0514:26.5 RDO-3	uh that's gate three, taxiway charlie and did not copy after that.
0514:30 HOT-1	why don't we go ahead and open the engine anti-ice, Dave, we're pickin' up a little bit ah ice *.		
		0514:37 RAMP	that oughta be taxiway Charlie, gate number two.
		0514:41.6 RDO-3	taxi charlie gate number two, got you [(loud 'n)/(a lot)] clear(er) now thank you.
		0514:45 RAMP	okay * you'll be facin uh south once you get parked there- [transmission stepped on by another radio transmission]
		0514:54.8 RDO-3	copy all, FedEx fourteen seventy eight.
0515:02 HOT-3	engine anti-ice is open.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0515:04 HOT-1	thank you.		
0515:05 HOT-3	uh, you are we are going gate two, taxiway charlie, and we're going to be facing south.		
0515:12 HOT-1	all right, know where it is, thank you.		
0515:14 HOT-3	CFIT [Controlled Flight Into Terrain risk assessment rating] is moderate and there is a required block time of forty four minutes.		
0515:18 HOT-1	okay.		
0515:27 HOT-2	one hundred scattered.		
0515:29 HOT-1	yeah.		
		0515:32 CTR	FedEx fourteen seventy eight, contact Jacksonville center, one three four point four five.
		0515:36.8 RDO-1	one twenty four forty five, so long FedEx fourteen seventy eight.
		0515:40 CTR	uh, one thirty four forty five.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
		0515:42.2 RDO-1	one thirty four forty five, good night, FedEx fourteen seventy eight.
		0515:52.3 RDO-1	Jacksonville center uh good morning, FedEx fourteen seventy eight, two nine oh, discretion to two four oh.
		0515:58 CTR2	FedEx fourteen seventy eight, JAX center roger, descend at pilot's discretion maintain niner thousand, Tallahassee altimeter three zero one zero.
		0516:05.0 RDO-1	discretion to nine thousand, three zero one zero, FedEx fourteen seventy eight.
0516:09 HOT-1	all right speeds-		
0516:10 HOT-2	nine thousand.		
0516:10 HOT-1	- when you're ready.		
0516:12 HOT-1	Vref one thirty seven.		
0516:14 HOT-2	yah.		
0516:15 HOT-1	uhhh bug at uh one forty seven.		

INTRA-COCKPIT COMMUNICATION | AIR-GROUND COMMUNICATION

TIME and SOURCE	CONTENT	TIME and SOURCE	CONTENT
0516:20 HOT-1	one fifty two, one sixty two... one ninety two, two oh two.		
0516:38 HOT-1	(zero fi-uh)- one thousand scattered, ten miles, uhh is zat what it said -		
0516:43 HOT-2	well we'll plan on uh-		
0516:44 HOT-1	-there?		
0516:46 HOT-2	-plan on a visual to runway two seven.		
0516:49 HOT-1	all right.		
0516:50 HOT-2	we'll back it up with this uh ILS runway two seven full procedure out to PALEE then a little teardrop...back into ah final, on one eleven point nine, two seventy two is the final approach course inbound.		
0517:06 HOT-1	roger.		
0517:09 HOT-2	ohhhh.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0517:13 HOT-2	glideslope intercept at um...looks like seventeen oh five, PALEE and we'll be at uh probably sss- eighteen hundred feet on the procedure...seventeen oh five glideslope inter-cept...(ahem) two hundred fifty...four on the orange bug.		
0517:32 HOT-1	(roger that).		
0517:37 CAM	[sound similar to short interruption in recording approx 0.4 second in length - all channels]		
0517:38 HOT-2	minimum safe is thirty three hundred feet all the way around... missed approach will be uh as published and we'll talk to 'em and see if we can get somethin' better.		
0517:47 HOT-1	okay.		
0517:48 HOT-2	published is eleven hundred, right turn to two thousand, direct uh, up to Seminole.		
0517:53 HOT-1	all right, very good.		
0517:54 HOT-2	runway's eight thousand...plan on rollin' out to the end gotta PAPI on the left hand side.		
0518:01 HOT-1	all right *.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0518:04 HOT-2	pilot controlled lighting so if you (can)... click it seven times I'd appreciate it.		
0518:09 HOT-1	definitely do that.		
0518:13 HOT-1	you gonna do that?		
0518:14 HOT-3	thanks.		
0518:15 HOT	[sound of squeak - first officer's channel]		
0518:19 CAM-2	turn the uh, ice off please.		
0518:23 HOT-1	what's that?... yeah I'm sorry yeah we can close it *.		
0518:30 HOT-2	all right, start on down.		
0518:31 HOT-1	all right.		
		0518:34.2 RDO-1	uh-Atlanta Fedex uh fourteen seventy eight, leaving two nine oh for uh, nine thousand.
		0518:40 CTR2	FedEx fourteen seventy eight, JAX, roger.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0518:43 HOT-3	engine anti-ice is closed.		
0518:47 HOT-1	(oh), thanks.		
0518:48 HOT-3	thank you.		
0519:28 HOT-2	[sound of clearing of throat]		
0519:38 HOT-2	you wanna land on nine if we see it?		
0519:42 HOT-1	uhhhhh.		
0519:46 HOT-2	we got a PAPI on nine, too.		
0519:48 HOT-1	yeah, maybe dat... it just uh... be a longer taxi for us but... way we're comin' in probly two seven be about as easy as any of 'em.		
0519:58 HOT-2	okay.		
0520:21 HOT-1	[sound similar to murmering]		
0521:57 HOT-2	in range please.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0521:59 HOT-3	altimeters?		
0522:01 HOT-1	set three zero one zero.		
0522:02 HOT-2	set at thirty ten.		
0522:04 HOT-3	set thirty ten.		
		0522:07 RDO	[sound similar to six microphone keyings over approx 1.3 seconds heard on Captain's and 2nd Officer's channels]
0522:08 HOT-3	airspeed bugs?		
0522:09 HOT-1	set.		
0522:10 HOT-2	[sound similar to coughing]		
0522:11 HOT-2	set.		
0522:13 HOT-3	EPR bugs?		
0522:15 HOT-1	G A.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0522:17 HOT-3	autopilot elevator servo?		
0522:19 HOT-1	system A.		
0522:20 HOT-3	in range checklist complete.		
0522:21 HOT-1	thank you.		
		0522:46 CTR2	FedEx fourteen seventy eight descend at pilot's discretion maintain three thousand.
		0522:50.8 RDO-1	discretion to three thousand, FedEx fourteen seventy eight.
0522:55 HOT-2	three thousand now.		
0522:56 HOT-1	(roger).		
		0523:33 CTR2	FedEx fourteen seventy eight, change to my frequency one three five point three two.
		0523:39.0 RDO-1	one thirty five thirty two, FedEx fourteen seventy eight.
		0523:49.2 RDO-1	and Atlanta FedEx fourteen seventy eight with you, one thirty five thirty two.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
		0523:54 CTR2	FedEx fourteen seventy eight, Jacksonville roger, and ah, you got the Tallahassee weather?
		0523:59.8 RDO-1	uh yes sir we do, FedEx fourteen seventy eight.
		0524:03 CTR2	roger expect visual approach (into) Tallahassee, report airport in sight.
		0524:06.5 RDO-1	FedEx fourteen seventy eight, roger.
0524:23 HOT-1	(let's see) runway nine * runway PAPI on the left side.		
0524:29 HOT-1	I don't know, you wanna try for nine?		
0524:32 HOT-2	we're pointed in the right direction, I don't know, like you said (it)... kinda a long # taxiback.		
0524:37 HOT-1	yeah, that'd be all right.		
0524:44 HOT-2	I always thought you were supposed to land with the prevailing wind.		
0524:48 HOT-2	at an uncontrolled... [sound similar to cough]		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0524:49 HOT-1	well at five knots it really uh ya know * * the only * the only advantage you have, landing to the west you have the glides- I mean to the west you have the glideslope... which you don't have to the east.		
0525:44 CAM	[sound of several clicks similar to low speed trim in motion]		
0526:41 HOT-1	you familiar with the airport here... at Tallahassee?		
0526:44 HOT-2	no, I'm not.		
0526:45 HOT-1	see the downtown area right there straight ahead?		
0526:47 HOT-2	yeah.		
0526:48 HOT-1	then if you go it looks like, just about sss- south southwest there's a little group ah lights down there.		
0526:53 HOT-2	ok.		
0526:54 HOT-1	there's a- you can see the beacon here in just a second right in that group ah lights right-		
0526:57 HOT-2	yeah I was just tryin'-		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0526:58 HOT-1	-there ya go.		
0526:58 HOT-2	-to see the beacon's right in the middle of the field, right?		
0527:00 HOT-1	ah yeah, um-hmm... right there.		
0527:04 HOT-2	*.		
		0527:29 UNK	[sound similar to monitoring of NAVIAD audio for approximatly 23 seconds, though Morse code is not clearly identifiable - Captain's Channel]
		0527:39.7 RDO-3	Tallahassee FedEx fourteen seventy eight.
		0527:44 RAMP	* Tallahassee OPS * * eight.
		0527:46.5 RDO-3	yeah Tallahasse, fourteen seventy eight five minutes out, hey quick question, you want APU or ground power?
0527:54 HOT-1	* PALEE is weak, * its startin to come in.		
0527:58 HOT-2	not very steady either.		
0527:58 HOT-1	naah.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	CONTENT	TIME and SOURCE	CONTENT
		0528:03 RAMP	* ground power.
		0528:05.8 RDO-3	okay fourteen seventy eight copies ground power, and if you could call transportation please, thank you.
		0528:12 RAMP	*.
0528:17 HOT-3	that'd be uh ground power when we get there.		
0528:19 HOT-1	thanks.		
0528:24 HOT-3	you want the approach checklist, seeing we're pretty much on our own, er?		
0528:26 HOT-2	we ever decide if we're goin nine or two seven?		
0528:28 HOT-1	yeah, we can do nine if you want to.		
0528:30 HOT-2	okay runway nine, visual runway nine PAPI on the left hand side... approach check.		
0528:35 HOT-3	briefing?		
0528:36 HOT-1	complete for runway nine.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0528:39 HOT-3	altimeters?		
0528:41 HOT-1	set uh, three zero one zero.		
0528:43 HOT-2	set, thirty ten.		
0528:45 HOT-3	minimums?		
0528:47 HOT-1	uhhh its set uhh well, its uhh set at... two fifty four now for uh-		
0528:52 HOT-2	two fifty four, nominal.		
0528:54 HOT-1	yeah.		
0528:57 HOT-3	approach checklist complete.		
0529:00 HOT-1	thanks.		
0529:48 HOT-1	four for three.		
0529:49 HOT-2	thank you.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0529:53 CAM	[sound similar to altitude alerter]		
0529:53 HOT-1	ehh you wanna call the field?		
0529:55 HOT-2	yeah. I don't see the runway yet, but I got the beacon.		
0529:58 HOT-1	yeah.		
		0529:59.6 RDO-1	Jacksonville, FedEx uh fourteen seventy eight, we have the airport.
0530:03 HOT-3	is it pilot controlled lighting?		
0530:04 HOT-1	yeah.		
		0530:05 CTR2	FedEx fourteen seventy eight cleared visual approach into Tallahassee, are you showing the uh NOTAM Tallahassee runway uh one eight three six is closed?
		0530:13.6 RDO-1	uh, no sir but uh, we're gonna use uh runway nine.
		0530:17 CTR2	all right you're cleared for the visual approach, and report your down time this frequency. if unable, to Gainesville radio, change to advisory approved.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
		0530:24.0 RDO-1	FedEx fourteen seventy eight, good morning.
		0530:32 RDO	[sound similar to five microphone keyings over approx 1.3 seconds - heard on Captain's, 1st and 2nd Officer's channels]
0530:39 CAM	[sound of several clicks over approx 6.5 sec period, similar to low speed trim in motion]		
		0530:39.1 RDO-1	Tallahassee uh FedEx fourteen seventy eight uh extended uh left base for runway nine.
0530:56 HOT-2	okay, I think I got a runway now.		
0530:58 HOT-1	all right.		
0531:04 HOT-1	runway should be just kinda su-		
0531:05 HOT-2	on the other side uh the uh-		
0531:06 HOT-1	- * that beacon there-		
0531:07 HOT-2	-beacon right?		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0531:08 HOT-1	-yeah, right... the other side of the beacon.		
0531:10 HOT-2	flaps two.		
0531:11 HOT-1	flaps two.		
0531:12.1 CAM	[sound similar to flap handle being moved]		
0531:17 CAM	[sound similar to high speed electric elevator trim wheel in motion]		
0531:22 HOT-2	flaps five.		
0531:23 HOT-1	flaps five.		
0531:24.1 CAM	[sound similar to flap handle being moved]		
0531:26 CAM	[sound similar to high speed electric elevator trim wheel in motion]		
0531:40 CAM	[sound similar to high speed electric elevator trim wheel in motion]		
0531:51 CAM	[sound similar to altitude alerter]		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0531:59 HOT-1	* * thousand * set (for/four).		
0532:34 HOT-2	well I hope I'm lookin' in the right spot here.		
0532:36 HOT-1	yeah you're lookin' uh see that group of bright lights kinda to the south down there and you see the beacon in the middle of it?		
0532:40 HOT-2	yeah.		
0532:41 HOT-1	that's right, right over there... you're kinda on ah about ah... uh I don't know probly ten mile left base or so.		
0532:47 HOT-2	okay so I was looking at the wrong # flashin-		
0532:49 HOT-1	yeah.		
0532:50 HOT-2	-light then.		
0532:51 HOT-1	yeah.		
0532:54 HOT-1	*.		
0533:04 HOT-1	* see it right out there at about-		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0533:05 HOT-2	oh yeah, I was lookin' at the wrong light.		
0533:07 HOT-1	* yeah okay, yeah.		
0533:40 HOT-2	yeah with the direction I took, we coulda used two seven, eh?		
0533:44 HOT-1	yeah, it dudn't matter.		
0533:48 HOT-1	yeah its about ten mile (basically) about ten miles south of the VOR.		
		0533:54.6 RDO-1	uh FedEx uh fourteen seventy eight, left base uh runway nine uh Tallahassee.
0534:04 CAM	[sound of several clicks]		
0534:11 HOT-1	I guess the lights came on, if not I'll click 'em again here... when we get * a little closer.		
		0534:31 RDO	[sound similar to five microphone keyings over approx 1.5 seconds heard on Captain's, 1st and 2nd Officer's chan-nels]
0534:35 HOT-1	there we go.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0534:45 CAM	[sound of click]		
0535:18 CAM	[sound similar to high speed electric elevator trim wheel in motion]		
0535:24 HOT-2	flaps fifteen please.		
0535:25 HOT-1	flaps fifteen.		
0535:27 CAM	[sound similar to high speed electric elevator trim wheel in motion]		
0535:31 HOT-2	gear down, before landing check.		
0535:33 HOT-3	'kay.		
0535:33 CAM	[sound similar to high speed electric elevator trim wheel in motion]		
0535:33.6 CAM	[sound similar to landing gear handle being operated, followed by sound similar to nose gear door opening]		
		0535:41.8 RDO-1	FedEx fourteen seventy eight turning uh final runway nine, Tallahassee.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0535:48 CAM	[sound similar to high speed electric elevator trim wheel in motion]		
0535:52 CAM	[sound of click]		
0535:54 HOT-3	landing gear?		
0535:56 HOT-1	down in three green.		
0535:57 HOT-3	check.		
0535:59 HOT-3	autobrakes?		
0536:00 HOT-1	ahhh...		
0536:02 CAM	[sound similar to 'flight control warning' horn]		
0536:02 HOT-1	that dudn't have either, uh... not installed.		
0536:06 HOT-2	flaps twenty five.		
0536:07 HOT-1	flaps twenty five.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0536:08 HOT-3	auto spoilers?		
0536:09 HOT-1	not installed.		
0536:10 HOT-3	FLIGHT and NAV instruments?		
0536:12 HOT-1	cross checked, no flags.		
0536:15 CAM	[sound similar to high speed electric elevator trim wheel in motion]		
0536:20 HOT-2	ehh sorry 'bout that-		
0536:20.2 GPWS	one thousand.		
0536:21 HOT-2	I was line'n up on that papermill-		
0536:22 HOT-1	oh that's allright nah-		
0536:22 HOT-2	-or something.		
0536:23 HOT-1	-that's all right no problem.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	CONTENT	TIME and SOURCE	CONTENT
0536:25 CAM	[sound similar to high speed electric elevator trim wheel in motion]		
0536:41 CAM	[sound similar to high speed electric elevator trim wheel in motion]		
0536:43 HOT-1	a-and you want thirty?		
0536:45 HOT-2	please.		
0536:45 HOT-1	yeah all right flaps thirty.		
0536:47.8 GPWS	five hundred.		
0536:49 HOT-2	(I'm) gonna have to stay just a little-		
0536:49 HOT-1	stable.		
0536:50 HOT-2	-bit higher, (or) I'm gonna lose-		
0536:51 HOT-1	yeah.		
0536:51 HOT-2	-the end of the runway.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0536:52 HOT-1	yeah okay.		
0536:52 HOT-3	flaps?		
0536:54 HOT-1	thirty thirty, green light.		
0536:56 HOT-3	landing clearance?		
0536:57 HOT-1	clear to land, runway uh... number nine.		
0536:58 CAM	[sound similar to high speed electric elevator trim wheel in motion]		
		0536:59.7 RDO-1	FedEx uh fourteen seventy eight short final runway nine, Tallahassee.
0537:09 HOT-1	it's startin' to disappear in there a little bit, idn't it.		
0537:10 CAM	[sound similar to high speed electric elevator trim wheel in motion]		
0537:12 HOT-1	think we'll be alright, yeah.		
0537:13 HOT-3	before landing checklist complete.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0537:14.0 GPWS	one hundred.		
0537:17 CAM	[sound of clunk]		
0537:19.9 GPWS	fifty.		
0537:20.3 GPWS	forty.		
0537:20.7 CAM	[sound of crunch]		
0537:21.0 GPWS	thirty.		
0537:22 CAM	[sound of crunch]		
0537:22 CAM	[sound of crunch]		
0537:22.6 GPWS	bank angle, bank angle.		
0537:23 CAM	[sound of crunching begins and continues to end of recording]		
0537:25 CAM	[sound of loud squeal begins and continues to end of recording]		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0537:26.2 CAM	end of recording		

[End of Transcript]

Appendix C
Correspondence Regarding the First Officer's Color Vision

DEPARTMENT OF THE AIR FORCE
USAF SCHOOL OF AEROSPACE MEDICINE (AFMC)
BROOKS CITY-BASE TEXAS

28 Mar 03

MEMORANDUM FOR NATIONAL TRANSPORTATION SAFETY BOARD
ATTN: MITCH GARBER, M.D.
490 L'ENFANT PLAZA EAST, SW
WASHINGTON DC 20594

FROM: USAFSAM/FECO
2507 Kennedy Circle
Brooks City-Base Texas 78235-5116

SUBJECT: [redacted]

1. The Aeromedical Consultation Service (ACS) of the USAF, School of Aerospace Medicine at Brooks City-Base Texas has completed our aeromedical evaluation on [redacted], a 44 y/o FedEx 727 pilot with a long standing known color vision (CV) deficiency who was involved in a nonfatal mishap along with two other crewmembers at Tallahassee, Florida on 26 Jul 02. Additional details regarding the final approach to Runway 09 at night and in clear weather are accounted for elsewhere; so only pertinent features related to our evaluation will be stated here.

2. [redacted] stated that he was at the controls of the aircraft and was using pilot-controlled PAPI lights during the approach. Although he stated that his memory lapse started about 10 miles prior to impact, he also stated that he was seeing the two white and two red light presentation on the PAPIs, but had provided "half a knob" of additional power when it appeared earlier that the aircraft was approximately one degree below glide slope. He stated that the aircraft was in a stable approach configuration, which was agreed to by all three crewmembers. He stated that he remembers continuing to see the two white and the two red light PAPI configuration. He further stated that he believed that there were indications discovered later that the PAPI lights may not have been operating optimally, but at the time of this evaluation, official verification of their operating condition was not available.

3. Historically, [redacted] had been a P3 Orion pilot in the Navy and had been qualified as a naval aviator on the basis of passing their primary CV screener, the Farnsworth Lantern (FALANT). At that time to our knowledge, the US Navy was not screening for CV deficiencies using Pseudoisochromatic plates (PIPs). According to routine procedures, he was requalified annually throughout his Navy flying career by the FALANT. [redacted] later received an FAA waiver without any flight restrictions in 1996 for his CV defect and recalls being tested with a plate test at that time.

4. At the time of the mishap, he stated that he was using over-the-counter dosage levels of Motrin for a knee injury, but could not recall the actual dose. He admitted to only taking two per day for about a 3-week period. However, as a consequence of serious injuries sustained during the mishap, he was now taking Coumadin for anti-embolic prophylaxis and Hydrocodone for pain, but had previously been on Oxycodone. He reported no other significant ocular history or medical history other than needing spectacles for near and distant vision correction.

5. The NTSB requested that CV testing at the ACS be done under pulse oxymetry to record his oxygen saturation levels during testing.

6. Examination Summary: Complete details of the ophthalmic evaluation will follow. However, a brief summary of the pertinent findings is covered in this letter. He had a small amount of myopia and presbyopia that were both correctable with spectacles to 20/15 O.U. for distance and 20/20 O.U. for near.

7. Color Vision Testing: During CV testing, his oxygen saturation was recorded to be between 98-99% by pulse oxymeter. All CV testing was performed monocularly in a darkened room under an approved illuminant and in compliance with individual test instructions and their appropriate time intervals.

a. PIP-I: [redacted] failed the Dvorine Pseudo-isochromatic plate test, which is a red-green congenital CV PIP screening test. To pass this test and to be regarded as color normal, an individual must have no more than four errors. On the first run, Mr. Frye could only correctly identify 2/14 correct OD and 3/14 correct OS. A repeat test, administered later, produced scores of 7/14 correct OD and 6/14 correct OS. Both of these test scores clearly reflect a failing score as per Dvorine's instructions and based on validation studies performed on that test.
b. PIP-II: [redacted] scored 9/10 correct in each eye on the Standard Pseudo-isochromatic Plate II (SPPII), which is a PIP test primarily optimized for acquired CV deficiencies, particularly blue-yellow. These are regarded to be passing scores on this test.
c. PIP-III: [redacted] scored 5/10 correct OD and 9/10 OS on the Standard Pseudoisocromatic Plate III (SPPIII) test. This PIP test is a combination of both congenital and acquired red-green and blue-yellow test plates. Based on these scores, he failed this test OD, but passed OS. Furthermore, he failed only red-green CV test plates OD.
d. Farnsworth F2 plate: This single plate test was designed by the Navy to screen for tritan defects. It has some ability to also identify deutans. [redacted] failed the test with a response consistent with a deutan.
e. D-15: [redacted] failed the test with a response consistent with a color-weak deutan. He revealed a pattern OD with only one minor transposition and had two minor transpositions OS. There was no major crossing defects suggestive of a deuteranope.
f. The FM-100: [redacted] failed the FM-100 with scores of 188 OD and 200 OS. Axis analysis revealed a pattern consistent with a deutan.
g. Nagel Anomaloscope: His performance on the Nagel anomaloscope was consistent with a severe deuteranomaly.

h. Spectrum Colour Vision Meter (Anomaloscope): His blue-yellow metameric match on the Moreland equation was normal, however, his performance on the red-green Rayleigh equation was consistent with a severe deuteranomaly.
i. Farnsworth Lantern (FALANT): He passed the FALANT with 9/9 scores in each eye.
j. The remainder of his eye exam was essentially within normal limits, with no evidence of either lenticular or retinal changes that would suggest an acquired CV defect.

8. A review of his CV testing battery revealed that all test results were consistent with a congenital severe deuteranomaly. This was based on the scores, symmetry, and consistency of his performance on a variety of red-green CV tests and ultimately was confirmed by two different anomaloscopes, performed by two independent examiners. The Motrin dosage he was taking at the time was not believed to be contributing to his CV deficit.

9. [redacted] did however "pass" the FALANT lantern. When developed, the FALANT was designed to pass approximately 30% of CV defectives (mild deficiencies), which were thought to be compatible with existing aviation tasks at the time. However, multiple studies of the FALANT indicate that it can misclassify even the most severe types of red-green CV deficiencies, and "pass" them. Consequently, it was dropped in 1993 as a secondary USAF qualifying test used in any applicant who failed an initial primary PIP screener. In [redacted] case, it also appears that the FALANT, did not correctly identify his CV deficiency throughout his entire Navy flying career, nor when administered here at the ACS. However, this notable test "pass" is inconsistent with all other CV testing we performed, but is consistent with a known testing inadequacy in the FALANT. Thus, we concluded that [redacted] has a severe congenital deuteranomaly and that this defect was not identified properly by the FALANT. This testing inconsistency with the FALANT has been previously documented in the literature.

10. When a variety of CV tests were evaluated by NATO-RTO and published in RTO Technical Report 16, "Operational Colour Vision in the Modern Aviation Environment" in 2001, the following observations were made.

a. "Even though lantern tests have been used for close to one hundred years, their validation and the availability of information on their reliability is almost nonexistent. The evaluation of most lantern tests and the failure rates associated with normals and CV defectives are either conflicting or simply insufficient. Test validation for this class of tests is both complicated and perhaps confusing. Cross validation of one lantern against another is confounded because of the differences in intensity, wavelength, target size and test distances."

b. "Validation of lantern tests by use of an anomaloscope has very rarely been attempted and cross correlation with plate tests has produced ambiguous results." In most cases, therefore, plate tests precede lantern tests with the notable exception of the US Navy where the Farnsworth lantern was used exclusively during this period of time.

11. Furthermore, we also believe that the type and degree of his congenital red-green defect could result in difficulties interpreting red-green and white signal lights that combine color and brightness, such as PAPIs and VASIs.

a. In 1973 Smith et al. applied a specialized technique to the evaluation of a group of deuteranomalous observers identified by the Nagel anomaloscope. Data relevant to this evaluation indicated that in the range from 510 to 660 nm, which is an area occupied by a considerable portion of the red system, under low light levels the hue was identified as "yellow" whereas when the light was brighter, it was identified as "white". Some observers did see a bit of red in the 660 nm range.

b. The PAPI light red filter produces "aviation red" as specified by MIL-C-25050. It's location in CIE space is at ca. 605 nm, which is in the middle of the red spectrum. Clearly, it is possible in this case, that the red lights of a PAPI could have been identified as "yellow" at lower light levels or "white" when the light was brighter.

12. However, his documented proficiency with over 8,000 flying hours suggests his performance using these devices could employ learned strategies, other than normal color discrimination, to "interpret" PAPIs. Our conclusions assume that the PAPI lights in operation at the time of the mishap were operating normally and were not providing errand information either in wavelength, brightness, or angle. The answer to this technical question, in addition to knowing details regarding the role of the other additional crewmembers, would be required before we could consider any further additional possibilities about the relationship and role of CV and other human or technical factors in this mishap.

Dr. John T Yates

JOHN T. YATES, Ph.D.
Chief, Visual Electrodiagnostic Laboratory

DOUGLAS J. IVAN, Col, USAF, MC, CFS
Chief, Aerospace Ophthalmology Branch

National Transportation Safety Board
Washington, D.C. 20594

Office of Aviation Safety

September 17, 2003

Douglas J. Ivan, Col USAF, MC, CFS
Chief, Aerospace Ophthalmology Branch
Department of the Air Force
USAF School of Aerospace Medicine (AFMC)
Brooks City-Base Texas

Dear Colonel Ivan:

I am writing in response to the aeromedical evaluation that your branch conducted in support of the NTSB investigation of the FedEx B-727 accident that occurred at Tallahassee, Florida on July 26, 2002. As summarized in your memorandum of March 28, 2003, your laboratory conducted extensive testing on the accident first officer's color vision and concluded that he suffered from a severe congenital deficiency in red/green color perception.

I am writing on behalf of the investigation to ask several further questions to clarify your findings and seek additional documentation regarding your evaluation of the first officer's color vision. The questions are:

1. In your memorandum, you stated that *"clearly, it is possible in this case, that the red lights of a PAPI could have been identified as 'yellow' at lower light levels or 'white' when the light was brighter."* Based on the evaluation:

    a) What is the likelihood the first officer would perceive the color red in a PAPI as white, and be unable to distinguish the red and white colors of the PAPI?

b) What is the likelihood the first officer would see the color red as "yellow?" If so, what would be his perception of the color white and would he be able to distinguish the two colors?

c) What is the likelihood that the first officer would perceive the color red in a PAPI as red, pink, or any color that might be readily distinguished from white?

2. You indicated that the first officer might *"employ learned strategies, other than normal color discrimination, to 'interpret' PAPIs."* What sort of learned strategies were you referring to?

3. Would the first officer have difficulty perceiving the color green in a display such as an airport identifier beacon, and differentiating this color from white and red?

4. How would the first officer's ability to discriminate between red and white colors on a PAPI be affected by day versus night viewing conditions?

5. How would the first officer's ability to distinguish red and white lights in a PAPI be affected when these signals were viewed under high relative humidity conditions (but not direct obscuration by fog)?

6. What factors would affect the first officer's color vision capabilities? Specifically:

   a) How would aging affect this type of color vision deficiency? That is, is it likel y that his color perception was better earlier in his career?

   b) How would hypoxia affect this type of color vision deficiency? Would his ability to discriminate red and white in a PAPI be affected? Would his ability to discriminate green from white be affected?

   c) How would smoking history affect this type of color vision deficiency? The first officer had a ½ pack a day smoking history for his entire adult life. He last smoked about three hours before the accident. Would this smoking history affect his ability to discriminate red and white in a PAPI? Would this smoking history affect his ability to discriminate green from white be affected?

   d) What other factors would affect the first officer's color vision capabilities and how?

7. The first officer received a perfect score on the Farnsworth Lantern test but failed all other red/green perception tests administered by your laboratory. How was he able to pass the Farnsworth Lantern test?

8. Can you provide any additional technical references concerning the validity of the Farnsworth Lantern test for color deficiency testing (including references regarding the

ability of pilots who pass the Farnsworth Lantern to reliably distinguish aviation signals and lights)?

9. Are you aware of any pilots with similar color deficiencies who have had careers in military or civilian aviation? Are you aware of any pilots with similar color deficiencies who have been involved in events/incidents/accidents related to their color vision? What color vision screening methods were used for these pilots?

10. Is it an accurate summary of your test results to state that the first officer was found to have a congenital color perception deficiency sufficiently severe that he could not reliably distinguish the red and white colors of the PAPI based on color information alone?

In your answers to these questions we would particularly appreciate any additional thoughts or evidence based on your evaluation of the first officer. In addition, any technical references applicable to assessing color vision discrimination capabilities in individuals with this type and severity of color deficiency would be appreciated. Thank you for the very thorough and thoughtful support you have provided so far and for your responses to this material.

Sincerely,

Malcolm Brenner, Ph.D.
National Resource Specialist—
Human Performance

DEPARTMENT OF THE AIR FORCE
USAF SCHOOL OF AEROSPACE MEDICINE (AFMC)
BROOKS CITY-BASE TEXAS

5 Nov 03

MEMORANDUM FOR NATIONAL TRANSPORTATION SAFETY BOARD
ATTN: MALCOM BRENNER, Ph.D.
WASHINGTON, DC 20594

FROM: USAFSAM/FECO
2507 Kennedy Circle
Brooks City-Base Texas 78235-5116

SUBJECT: FedEx B-727 Accident (July26, 2002), Tallahassee, FL;
NTSB ID #: DCA 02MA054

The USAFSAM evaluation of First Officer [redacted] in Feb 2003 identified him to have a severe deuteranomalous color vision (CV) deficit that most probably represented a congenital defect based on its long standing history, the characteristics of hi s defect, and the absence of any other identifiable conditions that would be consistent with an acquired etiology. At the request of NTSB, CV testing was done under monitoring by pulse oxymetry, which revealed normal hemoglobin oxygenation levels during testing. If First Officer [redacted] was alone in his visual interrogation and interpretation of the PAPI system, then it was the only available visible external cue he had to land the aircraft that night. With that in mind, we will now address the specific questions you have posed, in sequence:

1. His red-green CV discrimination was significantly impaired as identified on multiple red-green CV screening tests. Ultimately, he was characterized to be severely deuteranomalous, and nearly dichromatic, on anomaloscopic testing. Thus, compared to normal, his perceptible spectral bandwidth of colors would be quite narrow, likely approaching monochromatism above 540-545nm. This would essentially relegate him very nearly to a gray-blue-yellow world only. In that abnorm ally color shifted world, such an individual would have extreme difficulty, determining differences between greens and reds and many other colors to include whites based on wavelength or hue. The physiological nature of such a CV deficit is caused by an a bnormal shift in the wavelength sensitivity of the green cone system from it's normal position in the visible spectrum, towards, and nearly overlapping the wavelength sensitivity curve of the red cone system located at the longer wavelength section of the visible spectrum. A total shift would completely overlap the red cone system rendering such an individual dichromatic and a severe enough shift would also effectively render such an individual to be nearly dichromatic and still make red and green lights and most colors virtually

indistinguishable. Thus, the ability to appreciate differences in colors as normally generated by appropriate independent and simultaneous stimulation of normally separated red and green cone sensitivity curves would be severely compromised and abnormal. That independent stimulation of separate cone sensitivity curves located in different parts of the visible spectrum is required by the brain to determine appropriate matches that eventually define normal color perception. When the cone sensitivity curves abnormally overlap, wholly or in part, this ability becomes aberrant. The greater the overlap, the greater the problem. For example, conceptually, simultaneous stimulation of a single sensitivity curve by a purish source with a narrow wavelength range, such as a laser, would normally trigger only 1 cone system. However, with overlapping curves, that same light source would now be interpreted by the brain to be stimulating two different cone systems and be centrally processed to represent a color other than a purish red or green, because of the two cone systems now being stimulated (abnormally) at the same time and processed accordingly by the brain. Therefore, a light source or object that would appear to be red or green to a color normal would now appear to be something other than red or green to someone with this type of severe cone sensitivity shift, and more likely be interpreted as yellow. Therefore, because of the severity of his CV deficit, we believe that he would definitely have had problems discriminating the PAPIs normally, and as they were designed, because the red lights would appear not to be red at all, but either yellow, or some other wavelength, that would make them more indistinguishable from white, especially if the light sources were further intensified. Therefore, given the congenital near overlap of his red-green cone sensitivity curves, it would be extremely unlikely that he would be capable of seeing even the color pink on the PAPI, but more likely, a combination of whites and yellows and perhaps, not even that difference.

2. Congenital color defectives develop some ability to “differentiate” between normal colors based on clues other than hue or wavelength, such as by differences in shade or brightness. This is a learned process and is not reliable. Over time, they adjust to their “abnormal” color world and learn to assign typical color names to that perceived difference based on learned experiences. Such adjustments are not foolproof and are vulnerable to failure, especially when exposed to unpredictable and new color challenges without redundancy. Therefore, it might be possible for someone with this type of CV deficiency to use brightness differences between the white and red PAPI lights to help differentiate between them over an entire flying career. However, on the other hand, someone like this may also not have been able to use PAPIs effectively at all over their entire career, especially exclusively. If the "difference" between the white and red lights were somehow perceptible enough, someone could eventually learn how to use this information to analyze such challenges, but more likely, this would have caused such an individual to shy away from sole reliance on PAPIs. Such a strategy would be more effective in a CV defective, if the targets being interrogated, were limited, repeatable, and reproducible, such as in the Farnsworth Lantern (FALANT) or in the PAPI system, where learned strategies could be effectively tested by trial and error and employed. However, new and unexpected color tasks or lighting situations would be much more challenging or even impossible, to an individual with this level of CV defect, especially the first time encountered, than situations that can be uniformly

reproduced, retested, and represented over and over. That said, it is possible for an individual with this level of CV defect to quickly learn how to pass some color challenges based on limited selection options and other technical limitations, such as those known to be associated with the FALANT. Once someone learned how to assign a new color name for each particular brightness, or to any differences they might perceive, they could employ this strategy in order to "pass" the FALANT again and again. Remember, CV defectives have been trying to naturally adopt alternate strategies all their lives in order to adapt, function, and survive in their abnormal color world. However, we would expect that the first time someone with a severe red-green CV defect were administered the FALANT, that they would have had trouble truly passing it and would have needed time or additional testing to develop a strategy to "pass". To "pass" the FALANT, correct responses to the presentations are required. The testee is trying to "pass" the test, therefore, their goal is to give "correct" responses. Being unaware of normal colors and of their inability to truly identify hue based differences during the test, they would nonetheless try to give "correct" responses from their perspective based on how they have learned to differentiate between the choices. Therefore, they are trying to give the right answers without really being able to normally appreciate the differences as was intended by the test. They in fact know no other way and have had a lifetime trying to respond to color differentiation tasks that are obvious to color normals. Technicians are listening for responses and would not easily recognize "problems" beyond "right" or "wrong" responses. In fact, some may unintentionally "help" in the process. With only a known and limited number of colors and choices in FALANT combinations, and some adopted strategies that "differentiates" between the three, it can be conceived that such an individual could have consistently "passed" the FALANT using an alternate strategy, rather than actually being able to truly differentiate between the red, green, and white wavelengths as perceived by a normal trichromat. Paulsen et al.(1966), and others since have reported this. It should also be kept in mind that by design, the FALANT test was never designed to identify only color normals, but to allow some CV defectives to be passed and therefore be indistinguishable from true normals who also pass. However, it should not in theory pass more severe CV deficits, but unfortunately does so.

3. An individual with [redacted] type of CV defect is nearly a dichromat. As stated earlier, this means that the wavelength sensitivity curves of the red and green systems would be nearly overlapped, thus mimicking a single responding "red-green" cone system and true dichromatism. Consequently, such a red-green dichromat would be relegated to a world of grays, blues and yellows. Someone like him would be expected to have problems truly differentiating between red and green wavelengths, and in fact possibly all wavelengths greater than 545nm. Common errors include confusing whites with reds and greens, e.g., calling white lights red and vice versa.

4. His ability to see the PAPIs differently during the day or at night might vary depending on the intensity level selected for the PAPIs. Since the perception of the PAPI lights would be a photopic event in either case at these light levels, the same confusion would likely exist day or night, with one exception. Given the scenario he was under, at an unfamiliar airfield, at night, in a black hole with no other visual cues available for him to interrogate other than the PAPIs, published literature by Smith, et al.(1973) in similar CV defectives, including severe deuteranomalous individuals, clearly indicated that hues in the range between 500-600 nm were identified as yellow at reduced illumination levels, but when these wavelengths were intensified, the brighter colored lights were now interpreted as "white". In addition, low voltage levels of white PAPI lights are known to shift the white lights more towards yellow (Cole and Maddocks). This output driven wavelength shift would make it more difficult, or even impossible, for such CV defectives to distinguish differences between white, red, and yellow.

5. We do not have enough information available to us to answer this question. There are studies in the literature on atmospheric haze effects, but none that we could find on humidity.

6a. One of the characteristics of congenital CV defects is that they do not change over time unless an additional acquired etiology occurs and thereby overlays an additional component on the already underlying congenital defect. That would only make matters worse. The only age related issue that could possibly impact this case would be from any induced blue light filtration caused by the natural yellowing of the lens that occurs in everyone over time. This is a well-known UV-induced phenomenon that can induce an acquired blue-yellow deficiency by blocking shorter wavelengths, e.g., purples, and blues. We did not demonstrate any obvious cataract in his case, however, even a normal lens is known to have increasing levels of blue and UV filtration as a function of increasing age. Such an acquired blue-yellow CV disturbance would likely not aggravate existing red-green problems, however, could tend to aggravate the ability to distinguish residual differences between yellow and white, as this would be tantamount to wearing yellow lenses. However, he did not demonstrate an objective blue-yellow component at this point in time.

b. Hypoxia can definitely degrade visual function including color vision. This has been well established in the literature for years. The WW2 literature available from Schmidt identified increased pathological color thresholds (red and green both decreased in sensitivity, but in different subjects) with mild hypoxia above 9800 ft. and observed this to be even greater if there was an already existing color deficiency.

The following paragraph with respect to hypoxia and color vision was extracted from the Heino Widdel and David L. Post edited book entitled "Color in Electronic Displays", Defense Research Series, Vol 3, 1992:

"Several studies have reported that hypoxia results in losses in color sensitivity, although there is disagreement on the specific effects (see Dyer, 1988). When color vision has been tested foveally, the hypoxia generally produced a greater perceptual deficit for blue or green (Frantsen & Iusfin, 1958; Modugno, 1982; Schmidt & Bingel, 1953; Smith, Ernest & Pokorny, 1976; Weitzman, Kinney, & Luria, 1969); when it was tested peripherally, it generally produced a greater deficit for yellow or red (Blum & Fisher, 1942; Ernest & Krill, 1971; Kobrick, 1970; Vollmer, King, Fisher, & Birren, 1946). On the other hand, in testing the effects of hypoxia on the limits of the visual field, Kobrick, Zwick, Witt, and Devine (1984) found that the limits of green sensitivity decreased but not hose of red. Boles-Carenini and Cima (1952) noted that hypoxia worsened already-existing anomalies of the Nagel anomaloscope quotient."

Therefore, hypoxia could be expected to induce or further degrade any residual hue discrimination by raising the color sensitivity thresholds overall and reduce any residual wavelength discrimination across the visible spectrum. All colors become further degraded under lower levels of illumination, especially with hypoxia. These hypoxic effects have generally been studied using the FM100, but we could not find any other studies addressing hypoxia as a function of any other specific CV tests beyond those cited using the FM100 and Nagel anomaloscope.

c. Research has indicated that smoking also affects photopic vision, one aspect of which would be color perception. This can occur from related hypoxic and metabolic effects or from tobacco amblyopia, a type of chronic toxic optic neuropathy, usually seen in heavy smokers. Graefes (Arch Clin Exp Ophthal, 1999, May, pp 377-80) identified color vision changes in individuals who consumed more than 20 cigarettes per day.

d. Other potential factors that could affect anyone's color vision would include the nature, transmission characteristics, and color of any intervening optical interfaces, medications, drugs, and/or diseases that might also be present. These all would reduce brightness, change the spectral characteristics entering the eye or receptor sensitivities, and further degrade cone function. Our evaluation however did not reveal any known indication of any medications or diseases that would further impact his color perception in any way. A typical Boeing 727 windscreen would not normally be associated with any selective waveband filtration that would have further degraded the visual scene external to the cockpit in any significant way. However, specific FedEx modifications would need to be ruled out.

7. We believe that the First Officer was able to "pass" the Farnsworth Lantern using naturally learned strategies as previously discussed. His learned experience may have involved some early, unrecorded test failures and perhaps, some technician "assistance" along the way. This could have been as benign as allowing someone like him some additional opportunities to change a response or even retake the test. On the other hand, the FALANT is known to "pass" severe CV defectives, however that occurs.

Regardless, the FALANT was the only color vision test that he could "pass" at USAFSAM. All other test scores were consistent with a severe red-green deficit. The D15 was borderline. While this may appear disconcerting, it is not surprising and is consistent with known problems with the FALANT.

8. A database literature search would provide you with a complete bibliography with respect to the FALANT. In addition to references you already have, I would draw your attention to germane articles recently published in Aviation, Space, and Environmental Medicine in the last few years as a good start, as well as a few others linked below:

   (a) Birch and Dain, ASEM, Vol 70, No. 1, 1999.
   (b) Dain and Houson, ASEM, Vol 59, No. 4, 1988.
   (c) Laxar, Military Medicine, Sept, 1967, pp 726-731.
   (d) Cole BL and Maddocks, JD, "Colour Vision and PAPI", Colour Deficiencies XII, 1995, pp 501-510.
   (e) Cole and Vingrys, Documenta Ophthalmologica, 55, 1983, pp 157-175.

   The simulated PAPI Study by Cole and Maddocks (d) in particular identified unexpected problems with all deutans, both deuteranopes and deuteranomalous, that led them to conclude that proper recognition of PAPI systems by color defectives is problematic and a risk in aviation.

   Because of testing inaccuracies and other flaws of FALANT testing applicable to modern aviation, it was dropped as an official USAF aircrew qualifying test in 1993. It simply was not reliable and misidentified significant CV defectives. (See below).

9. Prior to 1993, and throughout the entire history of the use of the FALANT in the Navy and USAF, passing the test meant that you met applicable CV standards at the time and did not require any further CV testing. Therefore, since many color defectives can "pass" the FALANT, the true CV status of an individual who passes it, cannot be determined on the basis of passing that test alone. Procedurally, for decades, the USAF used a red-green PIP-I screener first, and then, only if you failed that test, were you administered the FALANT. If you failed the FALANT, you were disqualified. If you passed the FALANT, you were qualified and no further definitive quantitative analysis was required. PIP testing became the only standard used by the USAF between 1993 and 1995, when a transition to the present methodology was adopted.

   Currently the USAF uses a four-test battery of PIP plate tests to evaluate pilot applicants during Medical Flight Screening (MFS) for both congenital and acquired red-green and blue-yellow CV deficiencies. To qualify for MFS, an applicant must first pass an Initial Flying Class I exam including the traditional single red/green screening PIP test exam done in the field. The additional four test CV battery is then administered to all pilot candidates during MFS at USAFSAM. It comprises the PIP I, PIP II, PIP III, and the F2 plate tests. Failure of any one of those four PIP plate tests results in additional color vision (CV) testing to determine the exact nature and degree of any existing CV defect and a complete ophthalmological evaluation to rule out

acquired pathology. The final CV determinant test is the gold standard anomaloscope. However, many additional CV tests (FM100, FALANT, APT-5, D15, etc.) are also performed to monitor their effectiveness and correlation with the screening test battery and the anomaloscope, however, their results do not impact on the final waiver recommendation, only the anomaloscope results count at this point. This CV screening methodology is consistent with the recommendation of NATO's Working Group 24 that was published in RTO-TR-016 in 2001. Because of many problems related to lantern tests, WG-24 did not recommend using any lanterns for CV screening and assessment for modern aircrew. Previous published studies of the FALANT have revealed that it "passes" between 25-40% of all color defectives while in theory it was designed to only pass mild deficiencies. That proven unreliability was the fundamental reason why the USAF dropped it as a CV qualifying test in 1993. Repeated analysis of the FALANT results in CV defectives at USAFSAM indicate that the FALANT does not distinguish or predict the magnitude of the CV deficiency and passes mild, moderate and severe anomalous trichromats. It is usually failed by dichromats. More specifically, in the most recently analyzed data submitted for presentation for AsMA 2004, the FALANT passed 60% of subjects identified to have severe deuteranomaly on the anomaloscope.

Given intended and unintended flaws associated with the FALANT, it therefore remains unknown how severe a color defective might be if they "passed" the FALANT. There is some data however on this in the literature to include the additional experience here at USAFSAM with large numbers of applicants. Therefore, it is possible that aircrew with similar defects managed to escape accurate identification of their true CV performance because of "passing" the FALANT. It has been subsequently shown that some can have significant CV deficits.

An apparent paradox exists in that, because of the absence of any disastrous accidents, aviators may appear, and is often argued, to have performed "successfully" throughout their career. This perception is likely due to a myriad of circumstances, but would represent a spectrum to include not being appropriately challenged, or even being just plain lucky! Being "successful" therefore can be misleading in some cases, as we believe it appears in this case. That "success" may vanish if their CV deficiency gets challenged in a way that their handicap fails them. We are aware of another Navy aircraft mishap that can be attributed to a very similar scenario involving a CV defective, as severe as this case, who also apparently "passed' the FALANT many times over his career. Following a series of color vision misperceptions during a flight that resulted in the loss of the aircraft, that mishap pilot was later identified to also be severely red-green CV defective and quite similar to the type of the CV defect in this case. During the post accident investigation, he admitted that he had gotten "help" and used alternate strategies to "game" the FALANT in order to "pass" it. Technicians "helped" in assorted ways. Anomaloscope testing in his case also revealed a severe red-green deuteranomalous CV deficiency.

10. In summary, we believe that this case appears to be consistent with a true failure in CV testing methodology involving the FALANT's inability to properly identify a severe red-green CV defective who found himself in a scenario when the PAPI system was the, main and possibly only, clue available to help him successfully land the aircraft at an unfamiliar airfield, despite his past history of apparent "success". The failure to properly identify his CV deficit is consistent with one of the potential problems associated with reliance on the FALANT, and is further consistent with other research in CV defectives using colored lights similar to the PAPIs. In this setting, we believe he would not have been able to properly interpret the PAPI system as designed because of his severe congenital red-green color vision disturbance.

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